IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

APPELLANTS:	Dr. Martin Tank	CONFIRMATION NO. 7326
SERIAL NO.:	10/575,032	GROUP ART UNIT: 3737
FILED:	April 7, 2006	EXAMINER: Joseph M. Santos
TITLE:	METHOD AND MR APPARATUS FOR DETERMINING POSITION AND ORIENTATION INFORMATION, REFERENCED TO A PATIENT, OF MR IMAGES BY INDIVIDUALIZATION OF A BODY MODEL	

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Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

APPELLANT'S APPEAL BRIEF

S I R:

In accordance with the provisions of 37 C.F.R. §41.37, Appellant herewith submits his brief in support of the appeal of the above-referenced application.

TABLE OF CONTENTS

TABLE OF AUTHORITIES

Cases

REAL PARTY IN INTEREST:

The real party in interest is the assignee of the application, Siemens Aktiengesellschaft, a German corporation.

RELATED APPEALS AND INTERFERENCES:

There are no related appeals and no related interferences.

STATUS OF CLAIMS:

Claims 16-32 are the subject of the present appeal, and constitute all pending claims of the application. Claims 1-15 were cancelled. Each of claims 16-32 stands as being finally rejected in the Office Action dated July 18, 2011.

STATUS OF AMENDMENTS:

An amendment following the Final Rejection was filed on December 13 in order to correct a typographical error in claim 22, which formed the basis of an objection by the Examiner in the Final Rejection dated July 18, 2011. As of the date of filing of the present appeal brief, it is not known to the Applicant whether this amendment has or will be entered, but in view of the nature of the amendment (only correcting a typographical error), Applicant sees no reason why the amendment would not be entered pursuant to 37 C.F.R. §41.33(a) and 37 C.F.R. §1.116. Claim 22 as set forth in the Claims Appendix herein, therefore, embodies the aforementioned correction of the typographical error.

No other amendment was filed following the Final Rejection.

SUMMARY OF CLAIMED SUBJECT MATTER:

The claims on appeal include four independent claims, which are claims 16, 30, 31 and 32. Those independent claims are set forth below with exemplary citations to the drawings and specification for all significant limitations therein.

16. A method for determining information regarding position and orientation of magnetic resonance (MR) tomographic slice image exposures of a patient referenced to the patient (p. 7, lines 2-4), comprising the steps of:

obtaining a plurality of initial MR overview exposures of the body of a patient (p. 15, lines 6-7; Fig. 2);

electronically individualizing electronic data representing a predetermined, generalized, parameterized anatomical body model (p. 7, lines 8-9; Fig. 2) that is non-specific for any one patient (norm model NM, p. 25, lines 12-17; Fig. 4 and p. 7, lines 28-30), using said initial magnetic resonance overview exposures to produce an individualized body model that is individualized for said patient of whom the overview exposures were generated (p. 15, line 20 - p. 16, line 4); and

after obtaining said plurality of initial MR overview exposures, obtaining subsequent MR slice image exposures of the patient and, in a computerized processor, automatically electronically determining patient-referenced information indicating a position and orientation of said subsequent MR slice image exposures of the patient dependent on a relative position of said subsequent MR slice image exposures with respect to the individualized body model (p. 7, lines 18-19; Fig. 2 and p. 20, lines 1-16).

30. A non-transitory computer readable medium encoded with programming instructions in computer readable form that cause a computer to operate a magnetic resonance MR imaging apparatus to:

obtain a plurality of initial MR overview exposures of the body of a patient (p. 15, lines 6-7; Fig. 2);

after obtaining said plurality of initial MR overview exposures, electronically individualize electronic data representing a predetermined, generalized, parameterized anatomical body model (p. 7, lines 8-9; Fig. 2) that is non-specific for any one patient (norm model NM, p. 25, lines 12-17; Fig. 4 and p. 7, lines 28-30), using said initial magnetic resonance overview exposures to produce an individualized body model that is individualized for said patient of whom the overview exposures were generated (p. 15, line 20 - p. 16, line 4); and

after obtaining said plurality of initial MR overview exposures, automatically electronically determine patient-referenced information indicating a position and orientation of said subsequent MR slice image exposures of the patient dependent on a relative position of said subsequent MR slice image exposures with respect to the individualized body model (p. 7, lines 18-19; Fig. 2 and p. 20, lines 1-16).

31. A control device for operating a magnetic resonance MR tomography apparatus having a scanner adapted to receive a patient therein, said control device being programmed to:

obtain a plurality of initial MR overview exposures of the body of a patient (p. 15, lines 6-7; Fig. 2);

after obtaining said plurality of initial MR overview exposures, electronically individualize electronic data representing a predetermined, generalized, parameterized anatomical body model (p. 7, lines 8-9; Fig.

2) that is non-specific for any one patient (norm model NM, p. 25; lines 12-17; Fig. 4 and p. 7, lines 28-30), using said initial magnetic resonance overview exposures to produce an individualized body model that is individualized for said patient of whom the overview exposures were generated (p. 15, line 20 - p. 16, line 4); and

after obtaining said plurality of initial MR overview exposures, automatically electronically determine patient-referenced information indicating a position and orientation of said subsequent MR slice image exposures of the patient dependent on a relative position of said subsequent MR slice image exposures with respect to the individualized body model (p. 7, lines 18-19; Fig. 2 and p. 20, lines 1-16).

32. A magnetic resonance (MR) apparatus comprising:

an MR data acquisition unit (MR tomography apparatus 1 in Fig. 4; p. 24, lines 1-8);

a control unit (control device 5 in Fig. 4; p. 24, lines 9-18) configured to operate said MR data acquisition unit to obtain a plurality of initial MR overview exposures of the body of a patient (p. 15, lines 6-7; Fig. 2);

said control unit being configured to electronically individualize electronic data representing a predetermined, generalized, parameterized anatomical body model (p. 7, lines 8-9; Fig. 2) that is non-specific for any one patient (norm model NM, p. 25, lines 12-17; Fig. 4 and p. 7, lines 28-30), using said initial magnetic resonance overview exposures to produce an individualized body model that is individualized for said

patient of whom the overview exposures were generated (p. 15, line 20 - p. 16, line 4); and

said control unit being configured, after obtaining said plurality of initial MR overview exposures, to operate said MR data acquisition unit to obtain subsequent MR slice image exposures of the patient, and to automatically determine patient-referenced information indicating a position and orientation of said subsequent MR slice image exposures dependent on a relative position of said subsequent MR slice image exposures with respect to the individualized body model (p. 7, lines 18-19; Fig. 2 and p. 20, lines 1-16).

Figs. 1-4 as originally filed are submitted herewith as Exhibit A.

GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL:

The following issues are presented for review in the present appeal:

Whether the subject matter of claims 16-18, 21-24 and 28-32 is anticipated under 35 U.S.C. §102(b) by the disclosure of United States Patent No. 6195,409 (Chang et al., Exhibit B), and

Whether the subject matter of claims 19, 20 and 25-27 would have been obvious to a person of ordinary skill in the field of designing and operating medical imaging systems, under the provisions of 35 U.S.C. §103(a), based on the teachings of Chang et al., in view of the teachings of an article "Automatic Scan Prescription for Brain MRI," Itti et al., Magnetic Resonance in Medicine, Volume 45 (2001) (pgs. 486-494), Itti et al., Exhibit C.

ARGUMENT:

Anticipation of Claims 16-18, 21-24 and 28-32 by Chang et al.

In the subject matter each of the independent claims on appeal, a generalized body model, that is not specific to any one patient, is used as a starting point. Overview images of a particular (specific) patient undergoing an examination are obtained, and these overview images of the specific patient are then used to individualize the non-patient-specific body model to the specific patient undergoing the examination. From the resulting individualized body model of the specific patient, the position and orientation of images of slices of the specific patient are designated for use as diagnostic images in order to assist in the diagnosis or examination of the specific patient.

In substantiating the rejection of the aforementioned claims based on Chang et al., Appellant respectfully submits that the Examiner has incorrectly equated the "model" that is described in the Chang et al. reference with the "predetermined, generalized parameterized anatomical body model that is non-specific to any one patient" of the independent claims of the present application.

As is explicitly stated in the Chang et al. reference at column 4, lines 66-67, the "model" that is used in accordance with the procedure disclosed in the Chang et al. reference is an abstract description of the examination subject himself or herself, i.e., the examination subject that is currently undergoing an examination. The "model" disclosed in Chang et al., therefore, is, and must be, patient-specific, i.e., the model that is disclosed and used in the change reference must necessarily describe the person currently undergoing the examination in question.

This is in contrast to the predetermined, generalized parametized anatomical body model of the independent claims of the present application which, as noted above, is non-specific to any one patient.

Furthermore, the Chang et al. reference makes use of the aforementioned "model" (i.e., the abstract description of the current examination subject) by adapting that model to a "pattern model" (template). By contrast, in the subject matter of the independent claims of the present application, the anatomical body model is adapted to the examination subject with the use of the initially acquired magnetic resonance overview images.

Therefore, the use of the model described in the Chang et al. reference is completely opposite to the use of the anatomical body model disclosed and claimed in the present application. In Chang et al., the "starting point" is a body model that describes the specific examination undergoing an examination, and that body model is then adapted to a more generalized template. By contrast, in the subject matter of the independent claims of the present application, a generalized anatomical body model is used as the starting point, that is non-specific to any one patient, and that anatomical body model is then individualized according to a number of MR overview exposures of the current examination subject. This is necessary in accordance with the present invention because the resulting individualized is then used to determine the position and orientation of subsequent magnetic resonance slice image exposures of the patient that are obtained.

Moreover, the procedure disclosed and claimed in the present application is significantly more simple and less prone to error in the implementation thereof than the procedure disclosed in the Chang et al. reference. In the Chang et al. reference,

a model is generated from the overview images themselves, by extracting a model description from the overview exposures. Therefore, if the overview exposures embody image artifacts or have a poor acquisition quality, the resulting model will unavoidably, and possibly without being noticed, embody these deficiencies as well.

By contrast, in the subject matter disclosed and claimed in the present application, by starting with a parameterized, generalized body model, any errors or artifacts that may be present in the overview exposures either have only a subordinate role in generated the individualized model, or can be recognized relatively easily, because the ensuing adaptation then becomes very problematical.

Moreover, as noted above the individualized body model is used to determine the position and orientation of the subsequently obtained slice images, which is not disclosed or suggested in Chang et al.

In the First Final Rejection dated July 23, 2010, in response to these arguments made by the Appellant, the Examiner stated that it was not his intention to equate the "body model" in the claims of the application with the "reference template" in the Chang et al. reference, but rather to equate the body model with the abstract, schematic description of the subject (even though, in the Interview Summary dated November 14, 2011, the Examiner still referred to the "template"). Appellant believes that Appellant correctly understood the Examiner's previous rejection, and, as noted above, Appellant expressly argued that the Chang et al. reference does, in fact, begin with an Abstract model, but this Abstract model is nevertheless a model of the specific patient undergoing the examination, and therefore it is not and cannot be equated with the generalized parameterized anatomical body model in the claims of the present application, which, as noted above, is explicitly stated to be non-specific

for any one patient. As noted above, at column 4, beginning at line 48, the aforementioned "model" in Chang et al., despite being described as being an "abstract, schematic description" is nevertheless an "abstract, schematic description" of the *subject of interest* and, moreover, is formed from overview measurements of that subject. This unambiguously teaches that the "model" in Chang et al. is specifically and directly representative of the patient undergoing the examination, and cannot be equated with the model in the claims of the present application.

In the First Final Rejection dated July 23, 210, the Examiner also stated that the "generalized anatomical body model" is not claimed as a starting point in the claims of the present application. Appellant is unable to understand how the Examiner has reached that conclusion, because it is clearly stated that the individualized body model, which is *subsequently* acquired, is generated by applying overview images to the aforementioned generalized anatomical body model. Clearly, the generalized anatomical body model has to be initially available *before* the individualized body model, because the generalized anatomical body model is used to *create* the individualized body model.

The Examiner again responded to these arguments in the second, final Office Action dated July 18, 2011 by citing column 3, lines 46-54 of the Chang et al. reference. The Examiner stated that the Chang et al. reference "clearly discloses that an abstract model of the object of interest is matched with a reference template." Appellant submits that this statement of the teachings of Chang et al. does not contradict Appellant's previous argumentation, but rather only confirms that the "model of the object of interest" (*i.e.* an individualized, patient-specific model) is adapted to a "reference template."

The Examiner further stated "the abstract model contains individual subject information (such as size, location, orientation and structural information of the subject) . . .", but this statement is not correct, and in fact corresponds to the argumentation made by the Appellant that the "abstract model" is an individualized model. The Examiner then argues that the abstract model is later used to individualize the reference template (in Chang et al.). As noted above, the "reference template" in Chang et al. is used to adapt the "model of the object of interest", but the "model of the object of interest" in Chang et al. is a patient-specific model, not an abstract model. Regardless, the "model" disclosed in Chang et al. is not used in order to individualize the "reference template" but rather the opposite occurs.

The Examiner based this argument on column 3, lines 38-45 of Chang et al. This passage in Chang et al. states that the *localizer images* may also be *analyzed* to extract important structural information about the object of interest, such as the size, location, and orientation of the object or organ of interest, and of sub-objects of interest, *yielding an abstract, schematic description of the object of interest.*

As best understood, this paragraph in Chang et al. apparently concerns only the creation of the "abstract, schematic description of the object of interest," and thus of the "model" that is individualized for a specific patient, on the basis of the localizer. Despite the confusing use of the word "abstract" in this passage in Chang, et al., it could not be more clear that the overall description is extremely specific to the particular patient in question.

Moreover, this passage does not concern the aforementioned "reference template." Appellant is unable to find any other passages in Chang et al. that would

(allegedly) indicate that the "reference template" is individualized or somehow made patient-specific.

The underlying premise of the Examiner's rejection and comments therefore does not appear to be supported by the actual language in the Chang et al. reference.

An anticipating reference must describe all of the elements and limitations of the claim in a single reference and enable one of skill in the field of the invention to make and use the claimed invention. *Merck & Co. v. Teva Pharmaceuticals USA, Inc.*, 347 F.3rd 1367, 1372, 68 U.S.P.Q. 2nd 185 (Fed. Cir. 2003). Anticipation under 35 U.S.C. §102 requires that a single prior art reference disclose each and every limitation of the claimed invention. *Moba, B. V. v. Diamond Automation, Inc.*, 325 F.3d 1306, 1321, 66 U.S.P.Q. 2d 1429 (Fed. Cir. 2003), *cert. denied*, 540 U.S. 982 (2003).

A single reference must describe the claimed invention with sufficient precision and detail to establish that the subject matter existed in the prior art. *Verve, LLC v. Crane Cams, Inc.*, 311 F.3d 1116, 1120, 65 U.S.P.Q. 2d 1051 (Fed. Cir. 2002). The reference must describe the Appellants' claimed invention sufficiently to have placed a person of ordinary skill in the field of the invention in possession of it. *In re Spada* 911 F.2d 705, 708, 15 U.S.P.Q. 2d 1655, 1657 (Fed. Cir. 1990). A single prior art reference anticipates a patent claim if it expressly or inherently describes each and every limitation set forth in the patent claim. *Trintec Industries, Inc. v. Top-U.S.A. Corp.*, 295 F.3d 1292, 1295, 63 U.S.P.Q. 2d 1597 (Fed. Cir. 2002).

For the above reasons, Appellant submits that the Chang et al. reference does not disclose the steps or features of any of independent claims 16, 30, 31 and 32 as arranged and operating in those claims, and thus the Chang et al. reference does not anticipate any of those claims. For the same reasons, the Chang et al. reference does not anticipate any of claims 17, 18, 21-24, 28 or 29 depending from claim 16.

Obviousness Rejection of Claims 19, 20 and 25-27 Based on Chang et al. and Itti et al.

The above arguments concerning Chang et al. are applicable to this rejection as well. Each of claims 19, 20 and 25-27 adds further method steps to the method of independent claim 1. The Itti et al. reference does not provide any teachings that are relevant to the use of the template in Chang et al. as discussed above, and therefore even if the Examiner is correct with regard to the teachings of Itti et al., modifying the Chang et al. method in accordance with those teachings of Itti et al. still would not result in the subject matter of any of claims 19, 20 or 25-27.

The Federal Circuit stated in *In re Lee* 227 F.3d 1338, 61 U.S.P.Q. 2d 1430 (Fed. Cir. 2002):

> "The factual inquiry whether to combine references must be thorough and searching. ...It must be based on objective evidence of record. This precedent has been reinforced in myriad decisions, and cannot be dispensed with."

Similarly, quoting *C.R. Bard, Inc. v. M3 Systems, Inc.*, 157 F.3d 1340, 1352, 48 U.S.P.Q. 2d 1225, 1232 (Fed. Cir. 1998), the Federal Circuit in *Brown & Williamson Tobacco Court v. Philip Morris, Inc.*, 229 F.3d 1120, 1124-1125, 56 U.S.P.Q. 2d 1456, 1459 (Fed. Cir. 2000) stated:

> [A] showing of a suggestion, teaching or motivation to combine the prior art references is an 'essential component of an obviousness holding'.

In *In re Dembiczak,* 175 F.3d 994,999, 50 U.S.P.Q. 2d 1614, 1617 (Fed. Cir. 1999) the Federal Circuit stated:

> Our case law makes clear that the best defense against the subtle but powerful attraction of a hindsight-based obviousness analysis is rigorous application of the requirement for a showing of the teaching or motivation to combine prior art references.

Consistently, in *In re Rouffet,* 149 F.3d 1350, 1359, 47 U.S.P.Q. 2d 1453, 1459 (Fed. Cir. 1998), the Federal Circuit stated:

> [E]ven when the level of skill in the art is high, the Board must identify specifically the principle, known to one of ordinary skill in the art, that suggests the claimed combination. In other words, the Board must explain the reasons one of ordinary skill in the art would have been motivated to select the references and to combine them to render the claimed invention obvious.

In *Winner International Royalty Corp. v. Wang,* 200 F.3d 1340, 1348-1349, 53 U.S.P.Q. 2d 1580, 1586 (Fed. Cir. 2000), the Federal Circuit stated:

> Although a reference need not expressly teach that the disclosure contained therein should be combined with another, ... the showing of combinability, in whatever form, must nevertheless be clear and particular.

Lastly, in *Crown Operations International, Ltd. v. Solutia, Inc.,* 289 F.3d 1367, 1376, 62 U.S.P.Q. 2d 1917 (Fed. Cir. 2002), the Federal Circuit stated:

> There must be a teaching or suggestion within the prior art, within the nature of the problem to be solved, or within the general knowledge of a person of ordinary skill in the field of the invention, to look to particular sources, to select particular elements, and to combine them as combined by the inventor.

Appellants submit that the decision of the United States Supreme Court in *KSR International Co. v. Teleflex Inc.,* 550 U.S. 398, 127 S.Ct. 1727, 82 USPQ 2d 1385 (2007), and the United States Patent and Trademark Office guidelines for

applying that decision, support the position of the Appellants. That decision, although stating that it is not always required to point to a specific teaching in a prior art reference in order to substantiate a rejection under 35 U.S.C. §103(a), by no means approved ignoring the above long-standing precedent, and certainly did not represent a blanket overruling of that precedent. In the *KSR* decision, the Supreme Court stated, *under certain circumstances*, it may not be necessary to point to a specific passage in a prior art reference as evidence of motivation, guidance or inducement in order to modify that reference in a manner that obviates the patent claim in question. The Supreme Court stated that if a person of ordinary skill in the art can implement a *predictable variation* and would see the benefit of doing so, Section 103(a) likely bars patentability.

Nevertheless, the Supreme Court also stated that the requirement to find a teaching, suggestion or motivation in the prior art "captures a helpful insight." The Supreme Court stated that although common sense directs caution as to a patent application claiming as innovation the combination of two known devices according to their established functions, it can be important to identify a reason that would have prompted a person of ordinary skill in the art to combine the elements as the new invention does. The Supreme Court, however, stated that not every application requires such detailed reasoning. The Supreme Court stated that helpful insights need not become rigid and mandatory formulas. The Supreme Court only stated that if the requirement to find a teaching, suggestion or motivation is required in such a rigid, formulaic manner, it is then inconsistent with the precedence of the Supreme Court. In fact, the Supreme Court stated that since the "teaching, suggestion or motivation" test was devised, the Federal Circuit doubtless has applied it in accord

with these principles in many cases. The Supreme Court stated there is no necessary inconsistency between this test and an analysis conducted under the standards of *Graham v. Deere*. The Supreme Court stated the only error is transforming this general principle into a "rigid rule limiting the obviousness inquiry."

Therefore, Appellants submit this decision of the Supreme Court does not in any manner approve, much less require, the absence of a rigorous evidentiary investigation on the part of the Examiner in order to substantiate most rejections under 35 U.S.C. §103(a). Only under the somewhat unusual, and very limited, circumstances outlined by the Supreme Court in the *KSR* decision might the Supreme Court excuse the absence of such a rigorous evidentiary investigation in reaching a conclusion of obviousness under 35 U.S.C. §103(a).

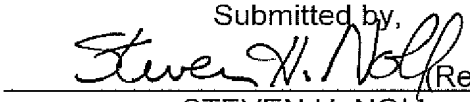
For these reasons, Appellant submits that none of claims 19, 20 or 25-27 would have been obvious to a person of ordinary skill in the field of designing and operating medical imaging systems, under the provisions of 35 U.S.C. §103(a), based on the teachings of Chang et al. and Itti et al.

CONCLUSION:

For the foregoing reasons, Appellant respectfully submits the Examiner is in error in fact and in law in rejecting claims 16-32 on appeal. Reversal of those rejections is proper, and the same is respectfully requested.

This Appeal Brief is accompanied by electronic payment for the requisite fee in the amount of $620.00.

Submitted by,



(Reg. 28,982)

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CLAIMS APPENDIX

16. A method for determining information regarding position and orientation of magnetic resonance (MR) tomographic slice image exposures of a patient referenced to the patient, comprising the steps of:

obtaining a plurality of initial MR overview exposures of the body of a patient;

electronically individualizing electronic data representing a predetermined, generalized, parameterized anatomical body model that is non-specific for any one patient, using said initial magnetic resonance overview exposures to produce an individualized body model that is individualized for said patient of whom the overview exposures were generated; and

after obtaining said plurality of initial MR overview exposures, obtaining subsequent MR slice image exposures of the patient and, in a computerized processor, automatically electronically determining patient-referenced information indicating a position and orientation of said subsequent MR slice image exposures of the patient dependent on a relative position of said subsequent MR slice image exposures with respect to the individualized body model.

17. A method as claimed in claim 16 comprising producing said initial magnetic resonance overview exposures in an arrangement according to a predetermined standard.

18. A method as claimed in claim 16 comprising generating said initial magnetic resonance overview exposures as cross-section exposures of the patient.

19. A method as claimed in claim 18 comprising generating said cross-section exposures, comprising said initial magnetic resonance overview exposures, as a plurality of cross-section exposures with respective intervals therebetween of no greater than 50 cm.

20. A method as claimed in claim 18 comprising generating said cross-section exposures, comprising said initial magnetic resonance overview exposures, as a plurality of cross-section exposures with respective intervals therebetween of no greater than 15 cm.

21. A method as claimed in claim 16 comprising, in said processor, automatically electronically determining a quality of individualization of said individualized body model by individualizing said anatomical body model in successive iterations and, after each iteration, comparing the individualized body model to a structure therein that is also detectable in said initial magnetic resonance overview exposures.

22. A method as claimed in claim 16 wherein said body model comprises body model parameters comprising at least one translation parameter, at least one rotation parameter and at least one scaling parameter of an entirety of the body model, in addition to parameters describing a spatial position and shape of predetermined body parts of said body model, and comprising individualizing said body model and adjusting at least one of said body model parameters.

23. A method as claimed in claim 16 comprising ,in said processor, generating a linguistic description of the position of the patient using parameter values of said individualized body model.

24. A method as claimed in claim 16 comprising automatically positioning said patient dependent on a patient description entered by an operator into said processor and, in said processor, automatically electronically monitoring said patient description using parameter values of said individualized body model.

25. A method as claimed in claim 16 comprising, from said processor, providing a visualizeable output of said position and orientation of said subsequent MR slice image exposures with respect to said individualized body model at a display in communication with said processor.

26. A method as claimed in claim 25 comprising providing said visualized output in a form selected from the group consisting of a linguistic form and a graphical form.

27. A method as claimed in claim 16 comprising using said individualized body model to automatically electronically calculate a body weight of the patient.

28. A method as claimed in claim 16 comprising automatically electronically using said individualized body model to position the patient relative to a magnetic resonance scanner, for obtaining said subsequent MR magnetic resonance exposures with respect to said individualized body model.

29. A method as claimed in claim 16 comprising electronically storing said individualized body model, and generating said subsequent MR magnetic resonance images of the patient at a time separated from a time at which said initial MR overview exposures of the patient were obtained, by electronically accessing the stored individualized body model.

30. A non-transitory computer readable medium encoded with programming instructions in computer readable form that cause a computer to operate a magnetic resonance MR imaging apparatus to:

obtain a plurality of initial MR overview exposures of the body of a patient;

after obtaining said plurality of initial MR overview exposures, electronically individualize electronic data representing a predetermined, generalized, parameterized anatomical body model that is non-specific for any one patient, using said initial magnetic resonance overview exposures to produce an individualized body model that is individualized for said patient of whom the overview exposures were generated; and

after obtaining said plurality of initial MR overview exposures, automatically electronically determine patient-referenced information indicating a position and orientation of said subsequent MR slice image exposures of the patient dependent on a relative position of said subsequent MR slice image exposures with respect to the individualized body model.

31. A control device for operating a magnetic resonance MR tomography apparatus having a scanner adapted to receive a patient therein, said control device being programmed to:

obtain a plurality of initial MR overview exposures of the body of a patient;

after obtaining said plurality of initial MR overview exposures, electronically individualize electronic data representing a predetermined, generalized, parameterized anatomical body model that is non-specific for any one patient, using said initial magnetic resonance overview

exposures to produce an individualized body model that is individualized for said patient of whom the overview exposures were generated; and

after obtaining said plurality of initial MR overview exposures, automatically electronically determine patient-referenced information indicating a position and orientation of said subsequent MR slice image exposures of the patient dependent on a relative position of said subsequent MR slice image exposures with respect to the individualized body model.

32. A magnetic resonance (MR) apparatus comprising:

an MR data acquisition unit;

a control unit configured to operate said MR data acquisition unit to obtain a plurality of initial MR overview exposures of the body of a patient;

said control unit being configured to electronically individualize electronic data representing a predetermined, generalized, parameterized anatomical body model that is non-specific for any one patient, using said initial magnetic resonance overview exposures to produce an individualized body model that is individualized for said patient of whom the overview exposures were generated; and

said control unit being configured, after obtaining said plurality of initial MR overview exposures, to operate said MR data acquisition unit to obtain subsequent MR slice image exposures of the patient, and to automatically determine patient-referenced information indicating a position and orientation of said subsequent MR slice image exposures

dependent on a relative position of said subsequent MR slice image exposures with respect to the individualized body model.

EVIDENCE APPENDIX

Exhibit A: Figs. 1-4 of the original application as filed on April 7, 2006.

Exhibit B: United States Patent No. 6195,409 – cited in the Final Rejection dated July 18, 2011.

Exhibit C: "Automatic Scan Prescription for Brain MRI," Itti et al., Magnetic Resonance in Medicine, Volume 45 (2001) (pgs. 486-494), Itti et al., Exhibit C.

RELATED PROCEEDINGS APPENDIX

None.

CH2\10794368.1

FIG 1

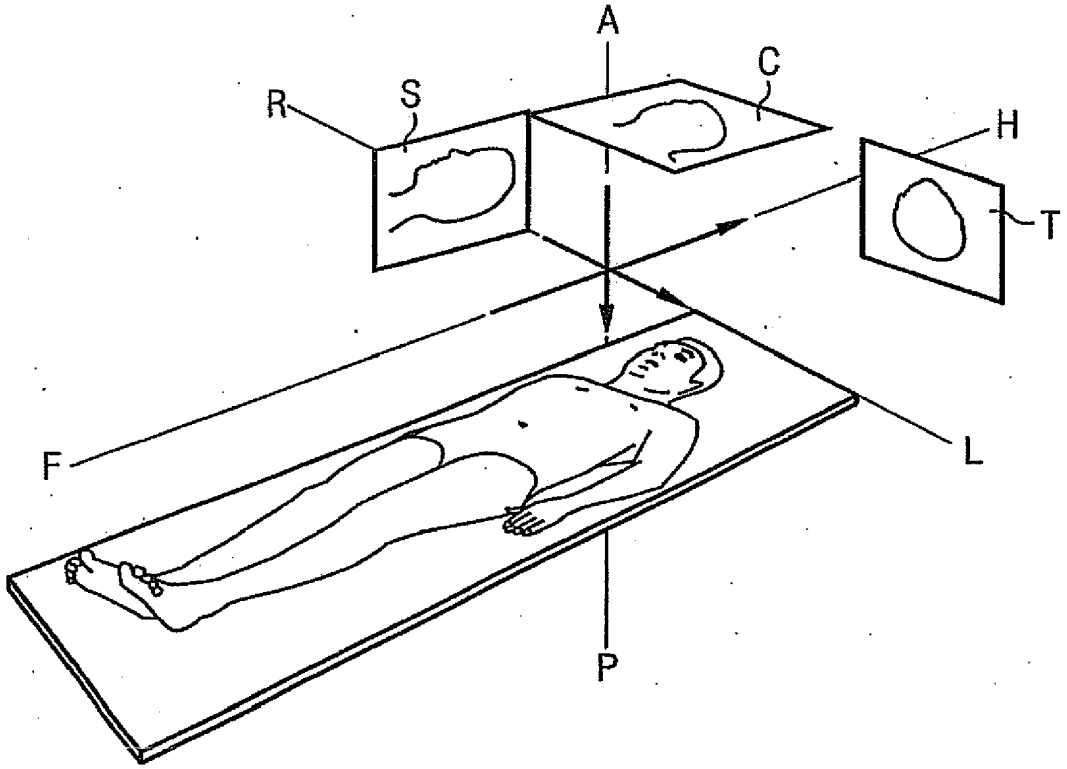


FIG 2

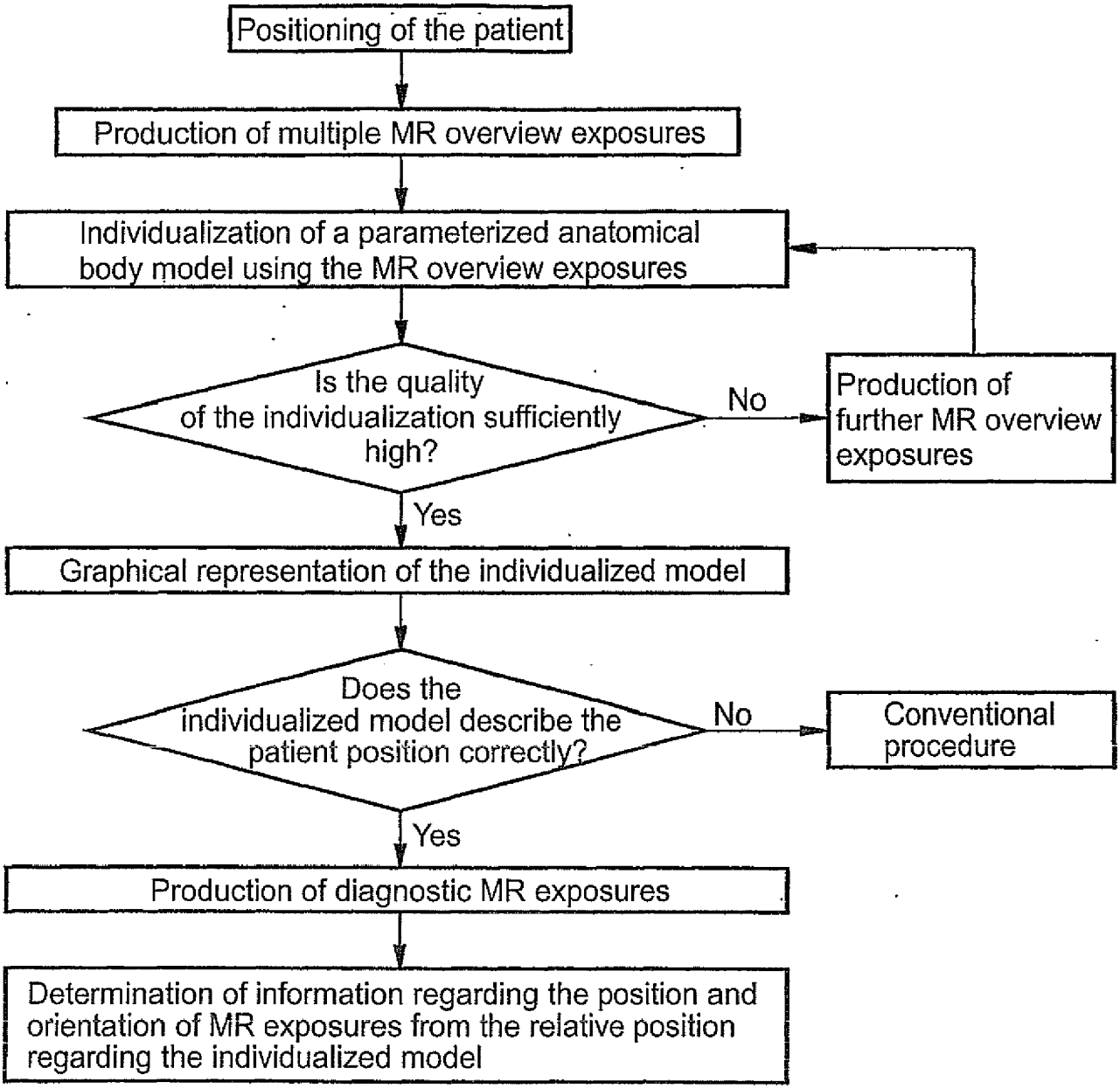

Positioning of the patient
Production of multiple MR overview exposures
Individualization of a parameterized anatomical body model using the MR overview exposures
Is the quality of the individualization sufficiently high?
No
Production of further MR overview exposures
Yes
Graphical representation of the individualized model
Does the individualized model describe the patient position correctly?
No
Conventional procedure
Yes
Production of diagnostic MR exposures
Determination of information regarding the position and orientation of MR exposures from the relative position regarding the individualized model

FIG 3A

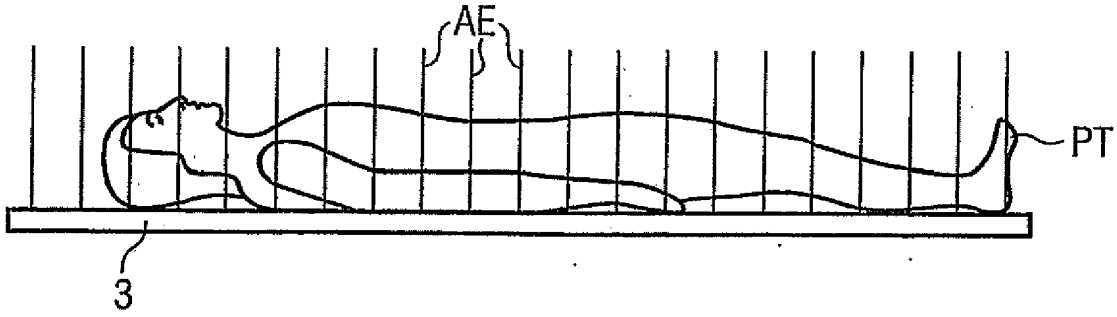


FIG 3B

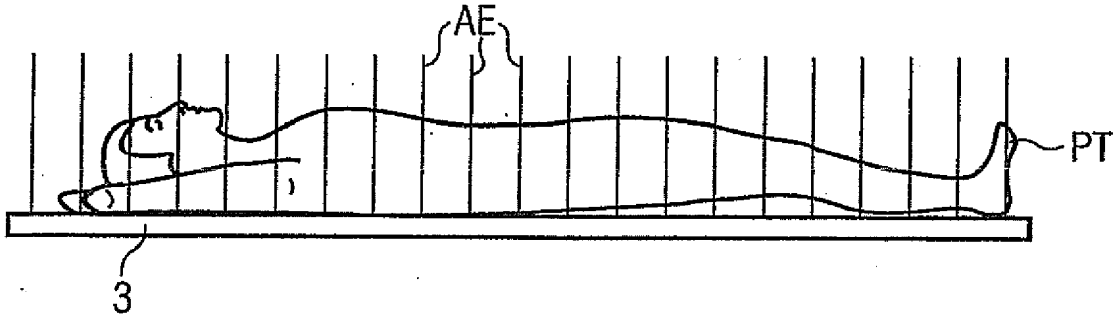
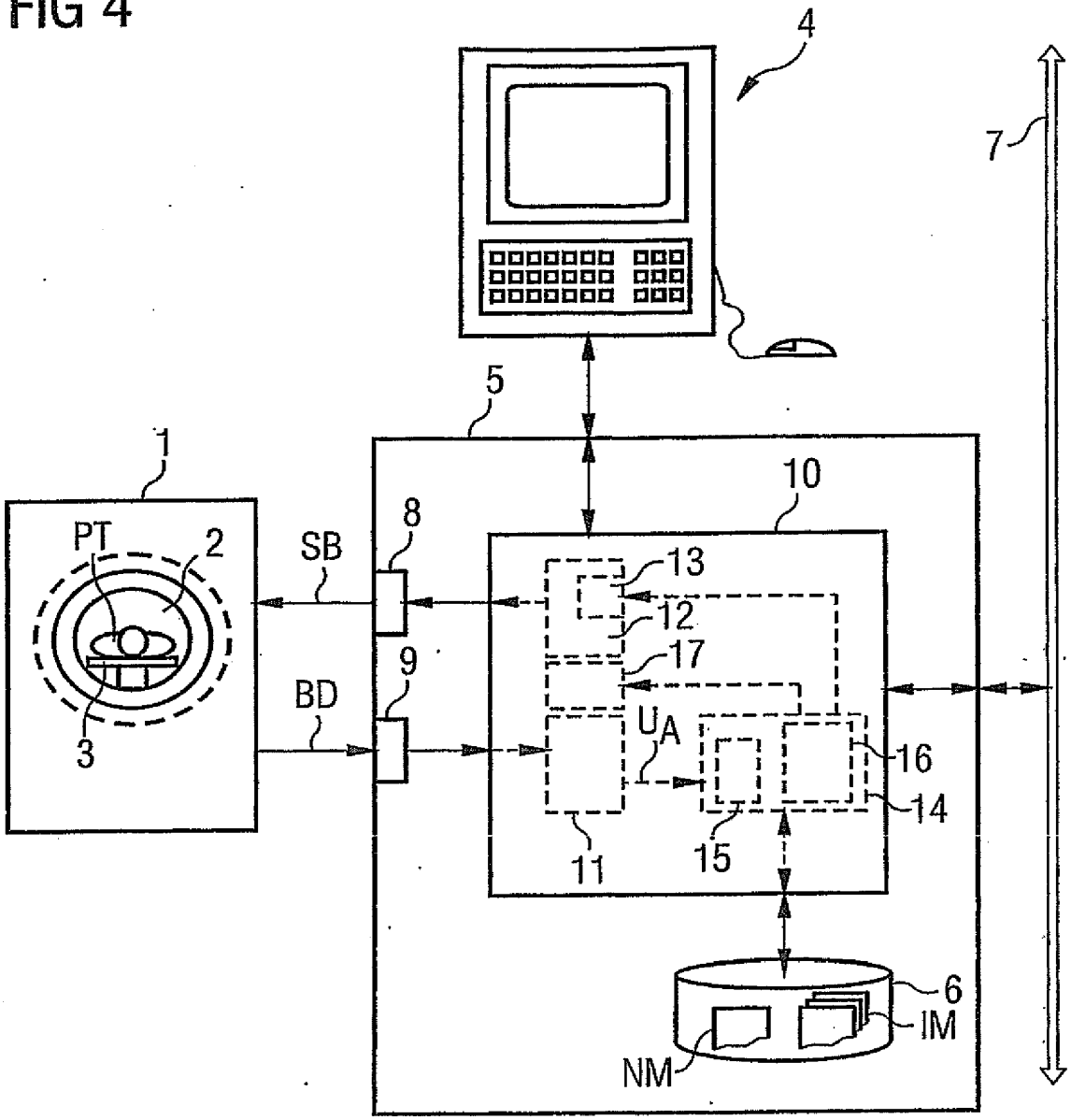


FIG 4



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Chang et al.

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(45) **Date of Patent: Feb. 27, 2001**

(54) **AUTOMATIC SCAN PRESCRIPTION FOR TOMOGRAPHIC IMAGING**

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(22) Filed: **Mar. 19, 1999**

Related U.S. Application Data

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(51) **Int. Cl.**[7] **A61B 6/03**

(52) **U.S. Cl.** **378/20**; 378/4; 378/8; 378/901

(58) **Field of Search** 378/4, 8, 20, 901

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(57) **ABSTRACT**

The system and method for automatic scan prescription involves initially performing at least one localizer scan for the object being imaged. The localizer images are analyzed to extract important structural information about the object of interest, and of subobjects of interest, yielding an abstract, schematic description of the object of interest. Optimal spatial locations and scanning parameters are then determined for subsequent scans from the information about the object, possible subobjects, and their relationship to a template. The locations for a particular scan included in a set of protocols selected by the operator are then communicated to the scanner in order to automatically drive the scanner. In a presently preferred embodiment, all of the analysis, matching, and scan prescription operations are preferably carried out by a microprocessor based microcomputer. Subsequent detailed and radiologically relevant scans can then be performed using optimal scanning parameters for the patient.

29 Claims, 2 Drawing Sheets

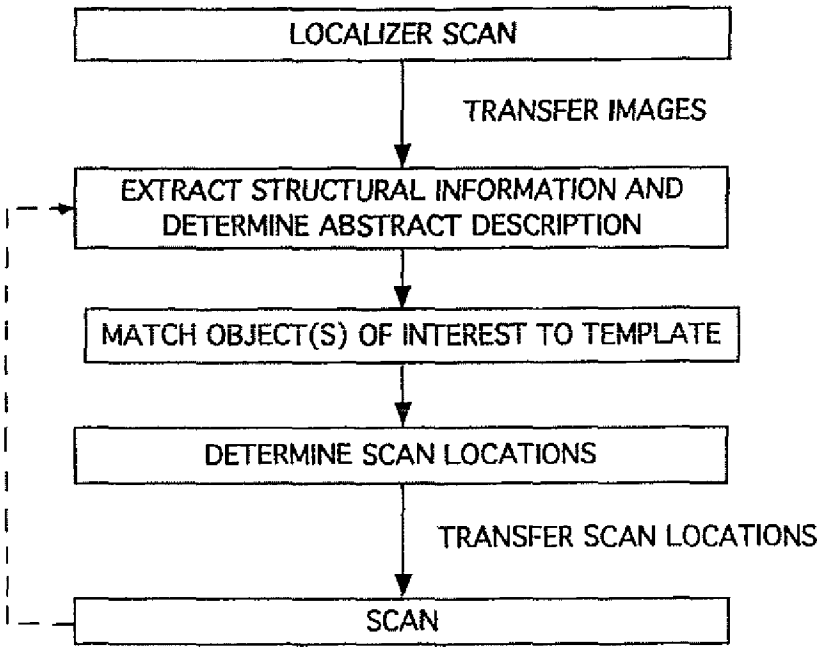
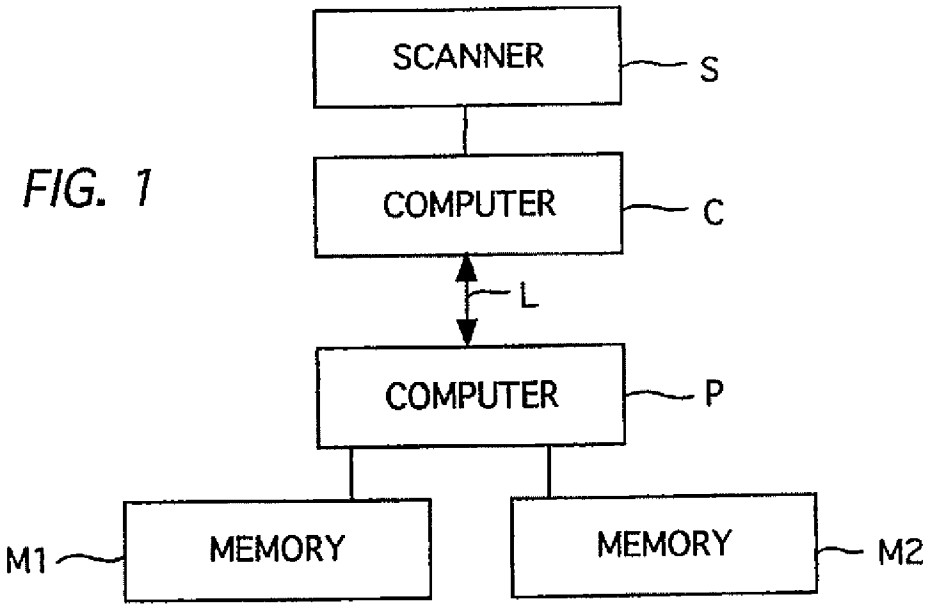


FIG. 1


SCANNER
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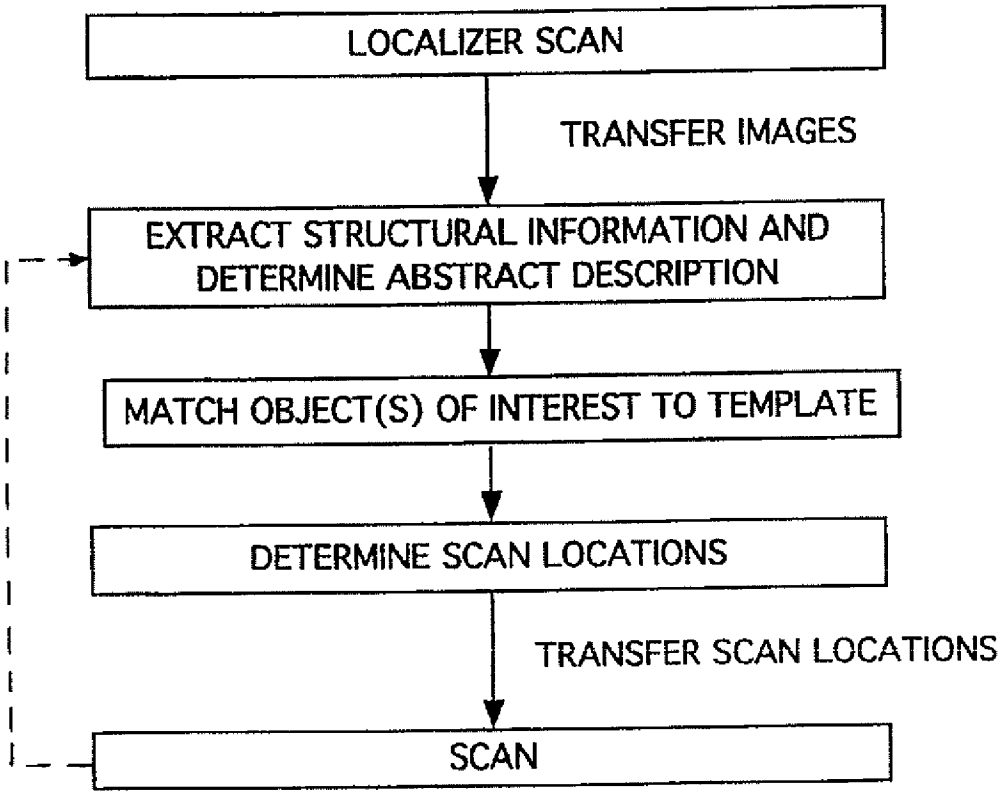
LOCALIZER SCAN
TRANSFER IMAGES
EXTRACT STRUCTURAL INFORMATION AND DETERMINE ABSTRACT DESCRIPTION
MATCH OBJECT(S) OF INTEREST TO TEMPLATE
DETERMINE SCAN LOCATIONS
TRANSFER SCAN LOCATIONS
SCAN

FIG. 2

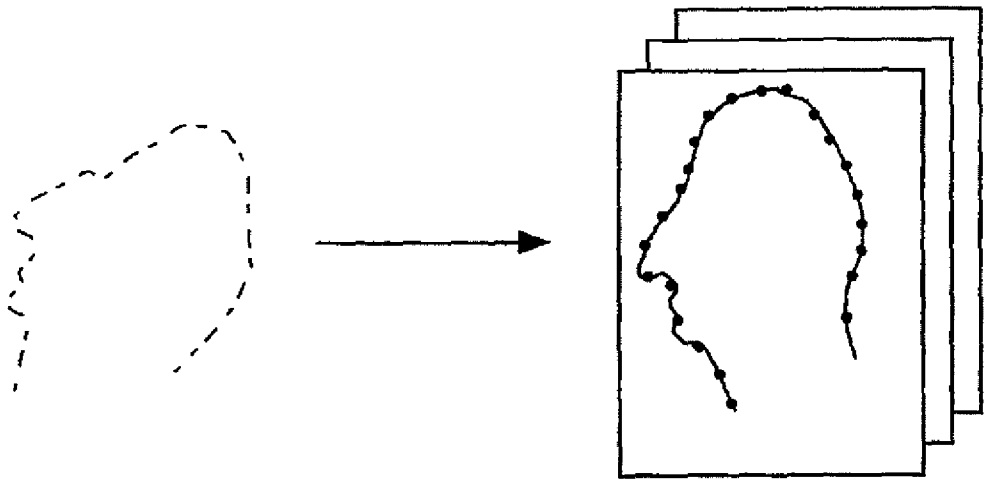

FIG. 3

AUTOMATIC SCAN PRESCRIPTION FOR TOMOGRAPHIC IMAGING

RELATED APPLICATIONS

This is based upon the provisional application Serial No. 60/086,401 filed May 22, 1998.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to medical imaging, and more particularly concerns a method for automatic scan prescription for tomographic imaging, such as magnetic resonance imaging (MRI), computer tomography (CT), and other tomographic imaging techniques. More specifically, the invention relates to methods to automatically determine scan orientations and locations for tomographic imaging scans.

2. Description of Related Art

In computerized tomography (CT), an image of a section or slice of a region of interest of a patient is typically obtained from a large number of narrow X-ray beam projections, at multiple angles through the slice, for providing multiplanar imaging of the patient. Modern CT scanners commonly provide a detector array mounted opposite the X-ray source, or a ring of detectors completely surrounding the region of interest of the patient, that sequentially detect the X-ray source as it is rotated around the patient. From the many individual measurements from the detectors, from either a single slice, a series of slices, or a helical scan, a computer is commonly used to fill in image data for a matrix of pixels with digital values representing the X-ray intensity measured during the scans.

While the human eye can only differentiate a limited number of shades of gray, computerized digital image data with much finer gradations can be utilized for identification and recognition of structures. One known X-ray computed tomography system is capable of specifying a slice plane corresponding to a desired tomographic image from a data base of helical or multiple scans of a subject. A scanogram of the subject is displayed, on which a cursor is controlled to identify the desired slice planes corresponding to the desired tomographic images to be reconstructed. The desired tomographic images are reconstructed for the desired slice planes indicated by the cursor by using an appropriate portion of the projection data, corresponding to the desired slice planes indicated by the cursor.

Another computed tomography system is known that includes an image reconstruction data generator for generating image reconstruction data for a desired slice plane of an object in accordance with projection data obtained at a plurality of rotation positions of a radiation source. The system also includes an image reconstructor for obtaining tomographic image data of the object for the desired slice plane, according to the image reconstruction data.

While CT can-be more advantageous for scanning bone structures than magnetic resonance imaging (MRI), MRI scanning is advantageous for imaging soft tissue structures, and can be used for multiplanar imaging of a patient. One such MRI imaging system is known, for example, for determining an MRI image plane, such as for imaging the head of a human being, in which the location of the plane of imaging, and its orientation are determined by computer analysis of the distance between manually selected points of the image, and the ratios of the distances between them.

Despite numerous advances in image processing of scanned images, tomographic scanning of patients for medical purposes is still generally performed according to manual prescriptions by specially trained medical technologists. In conventional tomographic imaging, prescription of scanning orientations, locations and angles requires a considerable amount of detailed input and control by the medical technologist. A typical scanning session begins with the acquisition of a "localizer" or "pilot" scan which provides an overview of major anatomical features, such as size and position, of a patient's body or body part to be scanned. Following the localizer scan, several additional scans are usually performed to gain more detailed information about the portion of the patient of interest. For each additional scan, the medical technologist uses the localizer scan or previous scans to manually define the boundaries and the orientation of the spatial volume to be scanned, such that it fully includes the region of interest.

Such conventional procedures for manually prescribing scan locations are relatively time consuming. As a result, human operators of tomographic imaging devices spend a considerable percentage of their time on this task, and are commonly unable to finish the manual prescription for a next scan before a current scan is finished, resulting in inefficient use of valuable scan time.

Currently, a scan technologist piloting the scanner equipment attempts to manually define scanning parameters that are appropriate for each individual patient. However, manual scan prescription by human operators is often crude, as the operators usually are not able to fully explore all degrees of freedom that need to be optimized in order to obtain the best possible scan. For example, many scanning parameters such as rotations of the tomographic imaging plane are kept at their default value. One of the consequences of this limited use of the available scanning parameters is an inaccurate, non-standardized prescription, yielding scan orientations that vary from one individual to another. With medical scans, such a variability in the scans makes interpretation of the scanned images by radiologists more difficult, and .may ultimately lead to reduced quality of radiologic readings.

Another consequence of the variability in the scan orientations is poor reproducibility for repeat scans, i.e., very different images are usually obtained when the same subject is scanned in different sessions, for example for follow-up of medical conditions, making direct comparison of scans from different sessions difficult.

It can thus be readily appreciated that there is a need for a method and system for automatic prescription of tomographic scans, according to standardized protocols, that minimizes the involvement of a human operator, and that permits reproducible multiple scanning of the same object or organ at different points in time. Such a method would be advantageous for providing accurate and reproducible prescriptions for studies that depend on one or more previous prescriptions. It would also be desirable to provide a method for automatic definition of specific regions of interest within a larger object or organ of interest in the tomographic imaging device for use with scanning methods to obtain information from the specific regions of interest, such as for localized magnetic resonance spectroscopy, for example, to obtain chemical information from within a well defined region of interest.

The present invention meets these needs.

SUMMARY OF THE INVENTION

Briefly, and in general terms, the present invention provides for a method for automatically prescribing scans for

tomographic imaging, and in particular for magnetic resonance imaging or computed tomography. The method of the invention for providing an automatic scan prescription allows faster, more reliable, more reproducible and more complicated scan prescriptions than are achievable manually by human operators. The system and method of the invention can be utilized in conjunction with a scanner, using a standard computer network apparatus, to communicate and automatically pilot the scanner. The system and method of the invention provide for fully automatic scan prescription and operation of a scanner, so that the only manual steps necessary for an operator to carry out a full tomographic study with multiple prescribed scans are to place a patient in a scanner and to select a clinical imaging protocol from a list of available choices.

The invention accordingly provides for a system and method for determining the orientation and location of standard tomographic scanning planes for automated scan prescription. Initially one or more initial localizer scans are performed. In one presently preferred embodiment, the one or more localizer scans may be used to determine a minimal bounding box for the object of interest to be imaged. The initial rapid localizer scan or scans can be, for example, a sagittal scan to determine the inferior/superior (I/S) range, i.e., a top and bottom range, and/or to determine the anterior/posterior (A/P) range of a bounding box for the object of interest. Alternatively, the initial rapid localizer scan can be an axial scan to determine the anterior/posterior (A/P) range, and/or the left/right (LR) range of the bounding box for the object of interest. As a further alternative, the initial rapid localizer scan can be a coronal scan to determine the left/right (LR) range or inferior/superior (I/S) range of the bounding box for the object of interest. This bounding box is defined as a rectangular boundary in terms of coordinates, and can then be utilized to prescribe further regular axial, sagittal or coronal scans. If a more special scan is necessary, another set of images can be obtained showing more detail.

The localizer images also may be analyzed to extract important structural information about the object of interest, such as the size, location, and orientation of the object or organ of interest, and of subobjects of interest, yielding an abstract, schematic description of the object of interest. For brain scans, such features may include, but are not limited to, the outer surface of the brain, the center locations of the eyes, and the locations of the brain commissures.

Significantly, the abstract, schematic description of (the "model") of the object of interest is then matched with a reference template of the abstract, schematic description of the object of interest that additionally contains information about the location of standard, optimal scanning planes, orientations and boundaries. Optimal spatial locations and scanning parameters can then be determined for subsequent scans from the information about the object, possible subobjects, and their relationship to the template. The locations for a particular scan included in a set of protocols selected by the operator are then communicated to the scanner in order to automatically drive the scanner. In a presently preferred embodiment, all of the analysis, matching, and scan prescription operations are preferably carried out by a microprocessor based microcomputer. Subsequent detailed and radiologically relevant scans can then be performed using optimal scanning parameters for that patient.

These and other aspects and advantages of the invention will become apparent from the following detailed description and the accompanying drawings, which illustrate by way of example the features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of the system for determining the orientation and location of tomographic scanning planes for automated scan prescription, according to the principles of the invention;

FIG. **2** is a flow chart of the computer software algorithms utilized in carrying out the invention; and

FIG. **3** is a schematic diagram of an initial level of matching of a skin contour of an image to a generic head shape.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Scan locations are usually prescribed by technologists, who manually define the boundaries and the orientation of the spatial volume to be scanned, such that it fully includes the organ of radiological interest. However, manual prescription of scan operations for tomographic imaging devices is time consuming, inefficient, and non-standardized, yielding scan orientations that vary from one individual to another, and that vary for a given individual from one scan to the next, making interpretation of the scanned images difficult.

Accordingly, as is illustrated in the drawings, and with reference to the attached Appendix containing source code for software utilized in the invention, the invention provides for a method for determining the orientation and location of tomographic scanning planes for automated scan prescription. Referring to FIG. **1**, the scanner consists of a tomographic imaging device, or scanner S, such as is generally available from General Electric, Siemens, Philips, and other manufacturers. The scanner is controlled by a computer, C. The device for automatic prescription consists of a computer P which is able to communicate with the scan computer C via a computer link L. Memory M1 of computer P holds one or more templates for scan prescriptions. Memory M2 of computer P holds a list of imaging protocols which may be selected by a human operator. For purposes of illustration, computer P and associated memory M1, M2, is shown to be physically different from computer C. However, computer P and associated memory maybe physically identical to computer C and associated memory, in which case computer C and computer P represent different processes orprograms within the same computer, and link L represents interprocess communication.

With reference to FIG. **2**, showing a flow chart of the method of the invention, in step **1**, an initial localizer scan of the object of interest is performed on the scanner S and computer C. The resulting localizer images are transferred to computer P via link L. In step **2**, the localizer images are analyzed in computer P to extract important structural information, such as size, location, and orientation, about the object and possible subobjects under consideration, yielding an abstract, schematic description (a "model") of the object of interest. In step **3**, a computer algorithm matches the abstract description (i.e. the model) of the object and subobjects of interest to the model of a template. In step **4**, the information about the object, possible subobjects, and their relationship to the template is used to determine scan locations. In step **5**, the scan locations are transferred back to the scanner to drive the scanner. The images from new scans may be used as additional localizer images, as indicated by an arrow pointing from step **5** to step **2** in FIG. **2**.

The "model" is an abstract, schematic description of the object of interest. The model consists of geometric infor-

mation in the form of "vertices" and possibly structural information in the form of "links" between the vertices and in the form of the "rigidity" of the links. The model thus corresponds to geometric and physical attributes of the object of interest. Each vertex of the model corresponds to a two or three dimensional set of coordinates identifying such features as the tip of the nose, an eye, brain commissures, and other similar reference points that correlate with anatomical structures. The vertices of the current patient are to be matched to be as close as possible to the corresponding vertices in the template. The links between vertices are defined in the form of vectors of distance or line segments, and a spring force identifying some physical relation between the points. The computer determines the vertices of the sample image according to model matching algorithms, further described below.

Several models or templates are used for the different steps or stages of the automatic scanning sequence. The initial levels of modeling are very gross, but very robust, and can be as simple as a bounding box or a surface contour of a magnetic resonance (MR) image, for example to a generic head shape, as illustrated in FIG. 3. This step may be used to determine head size and orientation in a fully automatic manner. Other models can be defined for the brain, brain structures, cranial structures, other organ structures, and the like. The models may be hierarchical; for example, a head model may include a boundary box, a skin surface model, a brain model, and an internal brain structure model. In a hierarchical system, an expert system checks various matching rules, such as checking matches of the vertices for the eyes, the skin contour, or brain commissures. In this manner, the model will predict that eyes will be in a certain location of an image, and evaluates whether the location of the image has image features similar to those for eyes, or for the skin contour, for example, by matching such features as brightness or intensity of the pixels at the location, and the shape of one or more groups of pixels at the location.

This allows for automatic quality control and makes the automatic scanning sequence robust.

Model matching uses geometric transformations (rigid or non-rigid) such that the model is moved, rotated, stretched, smeared or whatever other geometric transformation may be necessary to obtain a good fit between the generic model or template, and the particular image data. The steps in the transformation process are iterative, occurring for all of the possible transformations in tiny steps in loops. The rigidity of a link between two vertices of the model defines the strength of the relationship between the corresponding vertices. The rigidity of a link between two vertices generates a force, which depends upon the distance between the vertices. In one preferred embodiment of the invention, the force is mathematically similar to a spring force, in that the force of the link between vertices is increasing with the distance between the vertices. An energy balance of all of the spring forces and the changes in the distances between the vertices is determined for each step of the transformation process in conforming the model to the image, so that competition between the spring forces of the vertices counteracts unrealistic distortions of the models, and the looping of the transformation process continues as long as the forces do not completely balance.

The invention exploits several strategies and uses an expert system applying a set of rules prescribed by the operator to determine which strategy to apply. For example, an initial head orientation may first be estimated by fitting a bounding box, and then a skin contour model, and then a brain model. Next, the system could check whether the eyes are close to the location predicted by the model. If after proceeding through the possible matches, the match is determined to have failed, such as by achieving 7 positive matches and 3 negative matches out of 10, for example, the system can step through the various geometric transformations again and check the hierarchical matching, until a model transformation is found that satisfies enough of the quality control tests.

Once a sample is matched with a template, the various scanning planes of the sample image are determined from the known planes of the template, allowing the reliable, precise and accurate prescription of new scans for regions of interest in an automatic fashion.

A typical scan acquisition process can have the following sequence, for example. 1) The system scans the subject and acquires a sagittal, fall field image; 2) the image is matched to a bounding box model; 3) the image is matched to the skin surface, using a starting position for the skin model that is inferred from the bounding box; 4) selected internal structures are matched to a model of internal structures, using the skin contour model matching as a basis to infer the starting position of the internal structure model; 5) the position and location of the matched models are used to determine standard scanning planes, such as the orbital metal plane, the anterior commissures-posterior commissure line, and the scanning angles and boundaries for a prescribed scan for an region of interest.

For example, a fast spin echo (FSE) scan, an imaging sequence that is very rapid, was performed to study the brain of a subject, with scans being taken in the coronal, transverse and sagittal directions. The scans were utilized to create "water images" showing only pixels containing pure fluid, i.e. cerebrospinal fluid. From these images, an orbito-meatal plane (a standard reference line defined by the brain structures) and its rotation was identified, by co-registering the brain surface (from the images) with the reference brain with a known orbito-meatal line. Along the x-axis, the angle of orientation (γ) of the orbito-meatal plane of the current patient from the point of view of the scanner, i.e., the orientation of a scan along the orbito-meatal plane, was determined as the reference angle (ρ) plus the angle difference (α) between the reference and the current patient from co-registration, as follows:

$$\gamma=\rho+\alpha$$

where the reference angle ρ is the angle of the orbito-meatal plane in the reference images from the point of view of the scanner.

Planes may similarly be rotated about the y-axis or the z-axis if the head position is skewed, to adjust scans to match those known from the template. Also, by co-registering the image of the patient with a reference patient, spectroscopy voxels/pixels, such as for NMR spectroscopy, for example, can be prescribed in an automated fashion. It is also possible to use a gray/white segmentation to minimize or predetermine the grey/white content of voxel/pixel, i.e., to determine the chemical content of the gray/white matter. Similarly, scan planes can be placed for chemical shift imaging (CSI), a spectroscopy method, to scan multiple regions at one time.

Partial coverage of brain may also be obtained by coregistration. In certain situations, one may only want to scan certain subregions, such as the pituitary. In more complicated cases, the position may be obtained by complete segmentation to match a pituitary region to a template. It should be apparent that the principles of the invention can be applied to image processing of organs other than the brain.

For example, it is difficult to manually prescribe scan planes in the spinal cord, since it is bent; therefore, automatic prescription of the scan planes to follow the spinal cord would be an advantage. The scans used to extract information for automatic prescription are not limited to regular MRI sequences; more specialized scans, such as fat saturation scans, also may be used to extract anatomical information. Some pilot scans may be done using projection scans (full mass, i.e., of water in the brain), line scans, and the like, instead of fall three-dimensional scans. Echo planar imaging (EPI) is another extremely rapid scan technique, taking approximately 50 ms per scan, allowing 10–20 scans per second, that may also be suitable for use with the method of the invention.

It will be apparent from the foregoing that while particular forms of the invention have been illustrated and described, various modifications can be made of the invention. Accordingly, it is not t as by the appended claims.

What is claimed is:

1. A method for determining the orientation and location of standard tomographic scanning planes for automated scan prescription for a patient, the method comprising the steps of:

a) performing at least one initial localizer scan of a patient to provide images for the object of interest to be imaged;

b) analyzing the localizer scan images to extract important structural information about the object of interest to yield an abstract, schematic description of the object of interest;

c) matching said abstract, schematic description of the object of interest with a reference template of the abstract, schematic description of the object of interest;

d) determining optimal spatial locations and scanning parameters for subsequent scans based upon the relationship of the abstract, schematic description of the object of interest to the template;

e) communicating locations for a desired scan to a scanner in order to automatically drive the scanner; and

f) performing subsequent detailed scans to obtain detailed scan images based upon said optimal scanning locations and parameters for the patient.

2. The method of claim 1, further comprising the step of determining a minimal bounding box for the object of interest to be imaged from said at least one initial localizer scan.

3. The method of claim 1, wherein said at least one initial localizer scan comprises a sagittal scan.

4. The method of claim 2, wherein said at least one initial localizer scan comprises a sagittal scan, and further comprising the step of determining an inferior/superior range of said bounding box for the object of interest, based upon said sagittal scan.

5. The method of claim 2, wherein said at least one initial localizer scan comprises a sagittal scan, and further comprising the step of determining an anterior/posterior range of said bounding box for the object of interest, based upon said sagittal scan.

6. The method of claim 1, wherein said at least one initial localizer scan comprises an axial scan.

7. The method of claim 2, wherein said at least one initial localizer scan comprises an axial scan, and further comprising the step of determining the anterior/posterior range of the bounding box for the object of interest, based upon said axial scan.

8. The method of claim 2, wherein said at least one initial localizer scan comprises an axial scan, and further comprising the step of determining the left/right range of the bounding box for the object of interest, based upon said axial scan.

9. The method of claim 1, wherein said at least one initial localizer scan comprises a coronal scan.

10. The method of claim 2, wherein said at least one initial localizer scan comprises a coronal scan, and further comprising the step of determining a left/right range of the bounding box for the object of interest, based upon said coronal scan.

11. The method of claim 2, wherein said at least one initial localizer scan comprises a coronal scan, and further comprising the step of determining an inferior/superior range of the bounding box for the object of interest, based upon said coronal scan.

12. The method of claim 2, wherein said bounding box is defined as a rectangular boundary in terms of coordinates, and further comprising the step of prescribing at least one further scan selected from the group consisting of a regular axial scan, a regular sagittal scan, and a coronal scan.

13. The method of claim 1, wherein said step of analyzing the localizer images to extract important structural information comprises determining size, location, and orientation of the object or organ of interest.

14. The method of claim 1, wherein said step of analyzing the localizer images to extract important structural information comprises determining size, location, and orientation of a sub-object of interest.

15. The method of claim 1, wherein said reference template contains information about the location of standard, optimal scanning planes, orientations and boundaries.

16. The method of claim 1, further comprising repeating steps b)–f), utilizing the detailed scan images of step f) as the localizer scan images of step b).

17. A system for determining the orientation and location of standard tomographic scanning planes for automated scan prescription, comprising:

means for performing at least one initial localizer scan for the object of interest to be imaged;

means for analyzing the localizer images to extract important structural information about the object of interest to yield an abstract, schematic description of the object of interest;

means for matching the abstract, schematic description of (the "model") of the object of interest with a reference template of the abstract, schematic description of the object of interest;

means for determining optimal spatial locations and scanning parameters for subsequent scans from the information about the object, possible sub-objects, and their relationship to the template;

means for communicating the locations for a particular scan included in a set of protocols selected by the operator to the scanner in order to automatically drive the scanner; and

means for performing subsequent detailed and radiologically relevant scans using optimal scanning parameters for that patient.

18. The system of claim 17, further comprising means for determining a minimal bounding box for the object of interest from said at least one initial localizer scan.

19. The system of claim 18, wherein said at least one initial localizer scan comprises a sagittal scan, and further comprising means for determining an inferior/superior range of said bounding box for the object of interest, based upon said sagittal scan.

20. The system of claim 18, wherein said at least one initial localizer scan comprises a sagittal scan, and further comprising means for determining an anterior/posterior range of said bounding box for the object of interest, based upon said sagittal scan.

21. The system of claim 18, wherein said at least one initial localizer scan comprises an axial scan, and further comprising means for determining the anterior/posterior range of the bounding box for the object of interest, based upon said axial scan.

22. The system of claim 18, wherein said at least one initial localizer scan comprises an axial scan, and further comprising means for determining the left/right range of the bounding box for the object of interest, based upon said axial scan.

23. The system of claim 18, wherein said at least one initial localizer scan comprises a coronal scan, and further comprising means for determining the left/right (LR) range of the bounding box for the object of interest.

24. The system of claim 18, wherein said at least one initial localizer scan comprises a coronal scan, and further comprising means for determining the inferior/superior (I/S) range of the bounding box for the object of interest.

25. The system of claim 18, wherein said bounding box is defined as a rectangular boundary in terms of coordinates, and further comprising means for prescribing at least one further scan selected from the group consisting of a regular axial scan, a regular sagittal scan, and a coronal scan.

26. The system of claim 18, wherein said means for analyzing the localizer images to extract important structural information comprises means for determining size, location, and orientation of the object or organ of interest.

27. The system of claim 18, wherein said means for analyzing the localizer images to extract important structural information comprises means for determining size, location, and orientation of a sub-object of interest.

28. The system of claim 18, wherein said reference template contains information about the location of standard, optimal scanning planes, orientations and boundaries.

29. The system of claim 18, wherein said means for analyzing the localizer images, said means for matching, and said means for determining optimal spatial locations and scanning parameters comprise a microprocessor based microcomputer.

* * * * *

Magnetic Resonance in Medicine 45:486–494 (2001)

Automatic Scan Prescription for Brain MRI

Laurent Itti,* Linda Chang, and Thomas Ernst

Diagnostic brain MRI scans are usually performed by trained medical technologists who manually prescribe the position and orientation of a scanning volume. In this study, a fully automatic computer algorithm is described which compensates for variable patient positioning and acquires brain MRI scans in a predefined reference orientation. The method involves acquiring a rapid water-only pilot scan, segmenting the brain surface, and matching it to a reference surface. The inverse matching transformation is then used to adapt a geometric description of the desired scanning volume, defined relative to the reference surface, to the current patient. Both pilot scan and processing are performed within 30 sec. The method was tested in 25 subjects, and consistently recovered orientation differences between the reference and each subject to within ±5°. Compared to manual prescription, automatic scan prescription promises many potential benefits, including reduced scan times, reproducible scan orientations along anatomically preferable orientations, and better reproducibility for longitudinal studies. Magn Reson Med 45: 486–494, 2001. © 2001 Wiley-Liss, Inc.

Key words: MRI; registration; image processing; brain; scan acquisition; automatic

MRI scans are generally performed according to manual prescriptions by specially trained MR technologists. For instance, the determination of the location, size, and orientation of a scanning volume requires detailed input and adjustments by a technologist. A typical scanning session begins with the acquisition of a localizer or pilot scan, which provides an overview of the major anatomical features of a patient's organ to be scanned. The technologists then use the pilot scan to visually determine the location and orientation of scan planes for the subsequent series of high-resolution scans. However, manual prescription of scan geometry is relatively time consuming; for example, precise manual definition of scan orientation and boundaries can take up to several minutes when patients have unusual positions in the scanner. Therefore, operators often do not fully explore all degrees of freedom, such as 3D rotations, despite the relatively imprecise positioning of subjects in the scanner. Finally, manual scan prescription often is not reproducible as it suffers from both intra- and inter-operator variability—for instance, in defining the extent of anatomical coverage or the slice orientations. Consequently, MRI scans are typically performed in a non-standardized fashion, yielding scan orientations that vary from one patient to another. Therefore, there is a need for computer algorithms for the automatic prescription of MRI scans according to standardized protocols which could permit faster and more reproducible scans of the same organ at different points in time.

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In this work we present a software algorithm for the automatic prescription of MRI scans of the human brain. The method is related to existing algorithms for post hoc image coregistration and reorientation. Such algorithms have been widely used in research to determine the difference in orientation and position between scans acquired on one or several different machines. Typically, the orientation and position of one scan are iteratively adjusted until they match those of another scan (1). The matching criterion can be based on a measure of generalized distance between 3D surface outlines of the brain from both scans (2,3), on distances between external or anatomical landmarks (4,5), or on comparison of image intensities in overlapping brain regions (6,7). Rather than reorienting scans after data acquisition to match a common reference template, our method directs the scanner to acquire scans that natively match the geometry (i.e., scanning volume boundaries and 3D orientation) of the reference template. The algorithm automatically determines an optimal scanning geometry, defined relative to a template human brain, that matches the positioning and morphology of a patient. For every new patient a pilot scan is first acquired, from which the outer surface of the patient's brain is automatically extracted. By automatically matching the patient's brain surface to the template brain surface using coregistration, geometric information about the size, location, and orientation of the current brain relative to the template brain is computed. The resulting transformation between current and template brains is finally used to transform the location and orientation of optimal scanning planes, as defined in the template, to the current patient. Subsequent scans can then be acquired according to the desired scanning geometry and independently of patient positioning (Fig. 1).

METHODS

MRI Scans

All MRI scans were acquired on a 1.5 T whole body scanner (GE Signa 5.8, Milwaukee, WI) equipped with fast shielded gradients (SR 120). The method was developed and tested using scans from 13 volunteers (training data sets), and subsequently validated with no further modification of the algorithm on scans from 12 additional volunteers (test data sets). These 25 scans constitute all the scans acquired for the purpose of this study, and no scans were excluded from the analysis. First, a single-shot fast spin echo scan with fat suppression was acquired (TE 900 msec, 5 mm slices with 1 mm gap, 256 × 256 matrix, and 25 slices), which essentially shows signal from CSF only due to its extremely long TE. Although such a scan contains little anatomical information for human interpretation (Fig. 1), it can be acquired in a very short time (typically 10–20 sec) and provides sufficient information for an automated segmentation of the cortical surface.

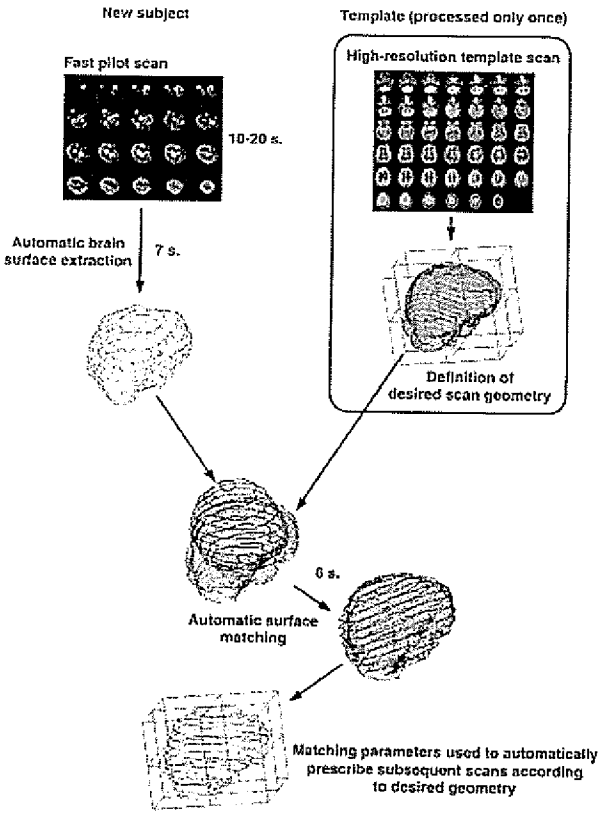


FIG. 1. Flow chart of the computer software algorithm utilized for automatic prescription of scan geometry. A reference template is created from a high-resolution MRI scan, and contains a brain surface and desired scanning geometry relative to that surface (top right). For each new subject (top left), a CSF pilot scan is acquired. The outer surface of the subject's brain is automatically segmented and matched to the reference surface. The 3D rotation resulting from matching the two surfaces is then used to transform the geometric description of the desired scanning volume from the reference to the current scan. Subsequent scans can finally be acquired according to this geometry, and will natively have a 3D orientation which matches that of the reference.

In three of the volunteers, the head was intentionally positioned in an extremely tilted position (see Fig. 2). Following off-line determination of the desired scan orientations, as described below, an additional validation scan was acquired according to the computed geometry. The validation scans used a segmented spin-echo echo planar imaging (EPI) sequence (TE 100 msec, TR 3000 msec, 5 mm slice with 1 mm gap, and 256 × 256 matrix).

Template

For the present study, a template was created containing a 3D geometric description of the outer surface of a human brain and a desired parallelepipedic scanning volume. The template brain surface was automatically segmented (3) from a high-resolution inversion-recovery scan of a normal volunteer (TR 4000 msec, TI 120 msec, TE 32 msec, 3.5 mm slices with no gap, and 256 × 256 matrix). The desired scanning geometry was defined relative to the template brain surface by manually selecting the 3D position, orientation, and size of a parallelepiped representing the volume to be scanned.

Image Processing

The algorithm to determine the spatial relationship between the brain in the current study and the template brain, and ultimately the slice plane orientations, was implemented as an extension of a customized coregistration software package developed in our laboratory (3,8,9). Typical processing times discussed in this study were obtained on a 500 MHz Compaq Alpha XP1000 Unix workstation. All algorithms described were written in language C.

The coregistration program is based on a two-step surface-matching algorithm. In the first primary step, the brain surface from the current CSF pilot scan is automatically extracted using an extension of the techniques described by Alpert et al. (10) and Mangin et al. (11). All processing is performed on a data set that is downsized by a factor of 2 in all three directions to reduce image processing time; hence, future pilot scans could be acquired at a lower resolution. Pixels with signal intensity outside the range of CSF intensity (e.g., background noise) are excluded using window thresholding: A pixel is considered CSF if its intensity is between 10% and 100% of the maximum intensity in the entire volume. The low threshold of 10% is chosen to include as much CSF as possible while excluding background noise. To avoid inclusion of the eyes in the brain segmentation, the eyes are eliminated using a 3D filter which maximally responds to a spherical object of 12-mm diameter on an empty background. The 3D convolution kernel for this filter hence contains values 1 inside the sphere and −1 outside. A threshold is applied to the result of the convolution to isolate the eyes, which are subsequently masked from the CSF scan. The resulting binary 3D volume within the accepted intensity range and with eyes removed is then subjected to isotropic 3D binary morphological dilation, with the objective of filling gaps in the outline of the brain derived from the CSF images. The morphological dilation operator replaces each non-zero pixel in the volume by a filled sphere of 3-cm diameter. Fast isotropic 3D dilation is obtained by thresholding an anisotropic chamfer distance map (3,12). Next, the dilated binary brain is isolated using an 8-connected 3D flooding algorithm, starting at the centroid of the dilated volume. As a result, non-brain structures with pixel intensities within the CSF range are eliminated. To recover the original brain size from the dilated and isolated binary brain, a 3D binary morphological erosion then is applied by thresholding an anisotropic chamfer distance map. Total processing time for this fully automatic brain segmentation is 7 sec.

In the second primary step, the brain surface from the current CSF scan is iteratively matched to that from the template. The surface from the current scan is considered mobile, whereas the template surface is a fixed reference. Therefore, 3D vertices are used to describe the current

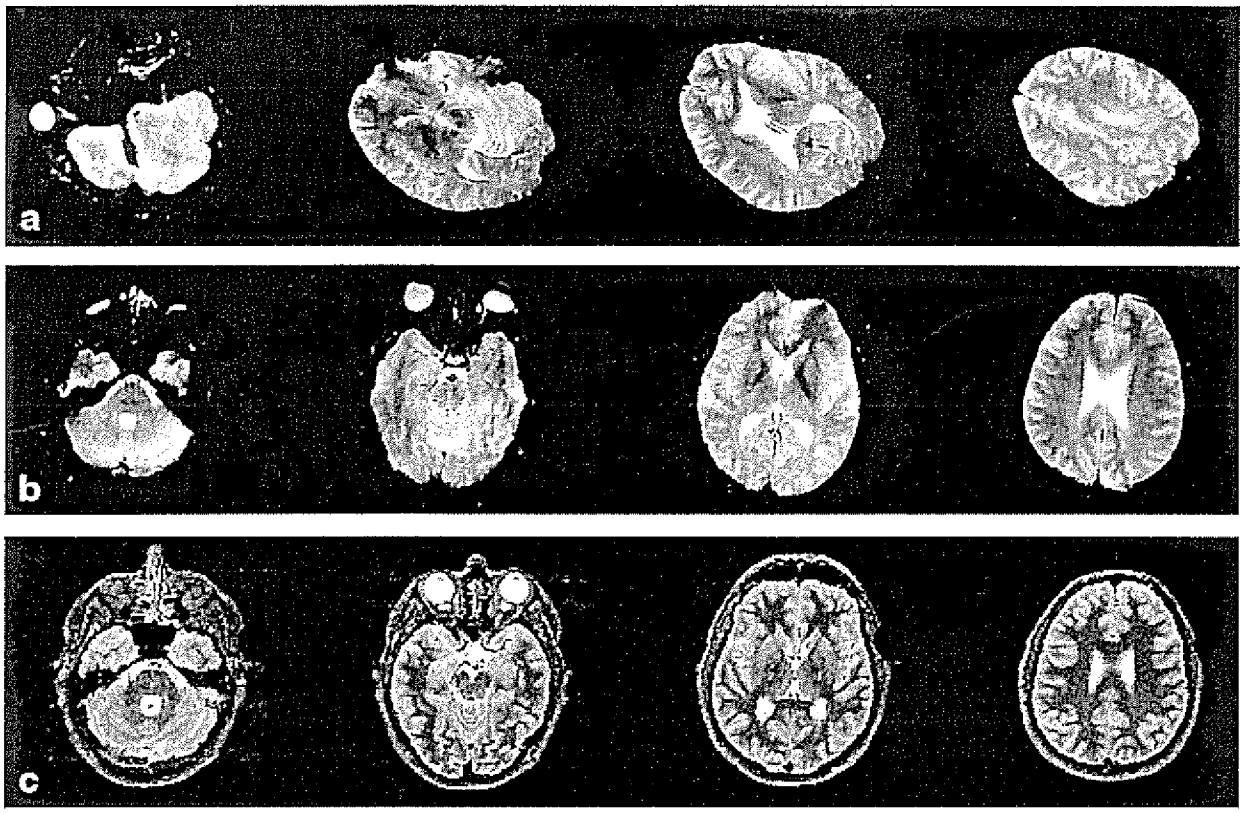


FIG. 2. MRI scans from a subject with markedly tilted head position, before (a) and after (b) adjusting the scan geometry. Note that the optimized scan (a) mirrors the slight rotation about the z-axis present in the reference template scan (c).

surface, whereas the template surface is represented by means of a chamfer distance map. Such a 3D distance map contains, for each pixel in a 3D volume, an approximation to the Euclidean distance between that particular pixel and the closest pixel on the template brain surface (3,13) (Fig. 3). Such a representation allows for fast computation of the distance between an arbitrary 3D vertex v and the closest point on the template brain surface, through a simple readout of the value in the distance map at the location of v (using trilinear interpolation). The computation of the distance map only needs to be performed once when the template is created, since it is associated with the template brain surface. To match the two brain surfaces, the vertices v of the mobile surface of the current patient, described by their 3D coordinates, are iteratively transformed to new vertices v′ using a 3D transformation with nine parameters:

$$v' = Av + T, \qquad [1]$$

where the vector T represents a translation (three parameters), and the 3×3 matrix A has six free parameters: three for rotations and three for scaling. The centers of mass of the two data sets are used to obtain an appropriate starting translation value for the iterative algorithm; the starting values for the rotations are 0 and those for scaling are 1. The mismatch between the two brain surfaces is then evaluated by calculating a generalized distance measure D from the locations of the transformed vertices v′ in the chamfer map. The distance measure is an approximation to the mean squared Euclidean distance between the vertices on the mobile surface and the reference surface. Thus, the generalized distance D provides a measure of the quality of fit between the two brain surfaces. Because the current CSF pilot scan may not cover the entire brain, the generalized distance measure D is defined in such a way that it is possible to match scans with incomplete overlap (3). Since the resulting distance measure may not be a continuous variable, Powell's minimization algorithm for nonregular functions is used to iteratively modify A and T in order to minimize the distance D between the two brain surfaces (14).

This initial surface matching is further refined using an alternate distance map; the convergence point of the initial matching is used as a starting point. The alternate distance map is identical to the original distance map except that it contains voids in the nasal sinus region (Fig. 3); consequently, the second surface matching step is insensitive to the inclusion of the sinuses in the mobile brain surface. This is necessary because large amounts of fluid in the nasal sinuses of a few subjects, due to sinusitis, were included in the initial brain segmentation. A similar strategy could be used to render the matching process insen-

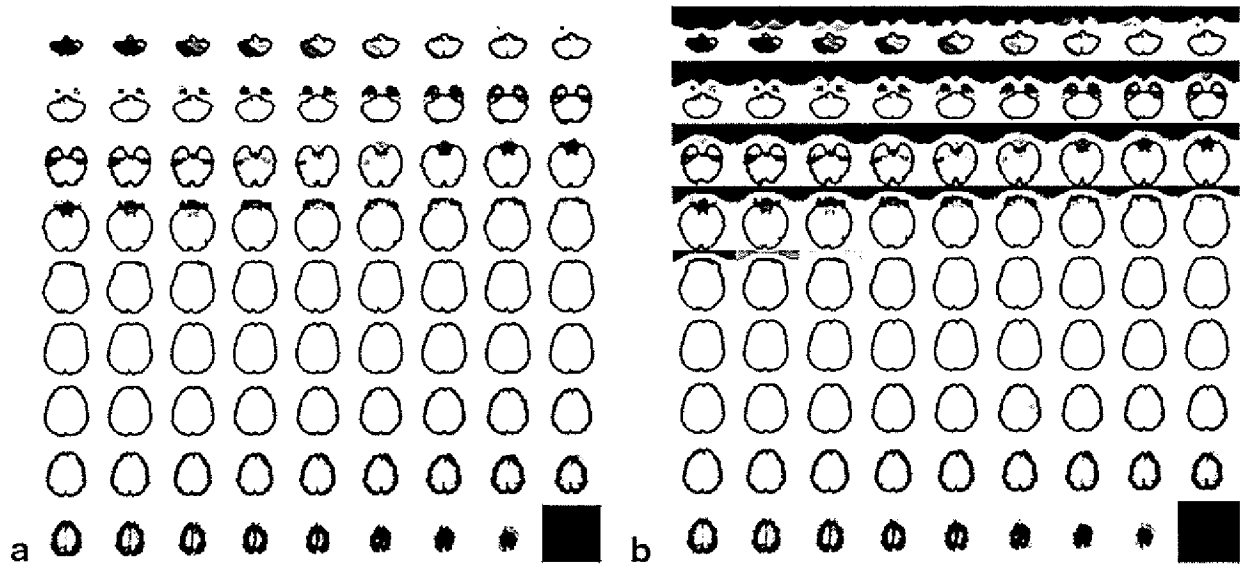


FIG. 3. Anisotropic chamfer distance map associated with the reference template brain (a). For each location the intensity in the map represents an approximation to the Euclidean distance between that location and the nearest location on the reference brain surface. In a refined version of the distance map (b) we have manually set the distance to zero (black) in the region of the nasal sinuses; vertices from the mobile surface falling in this region will thus be ignored during the computation of the generalized surface matching measure D. This modification renders the surface matching algorithm insensitive to segmentation artifacts in the region of the nasal sinuses. Similar modifications of the distance map could be used to render the algorithm robust to other classes of common structural abnormalities.

sitive to other segmentation artifacts. The total processing time for both surface matching steps is less than 6 sec.

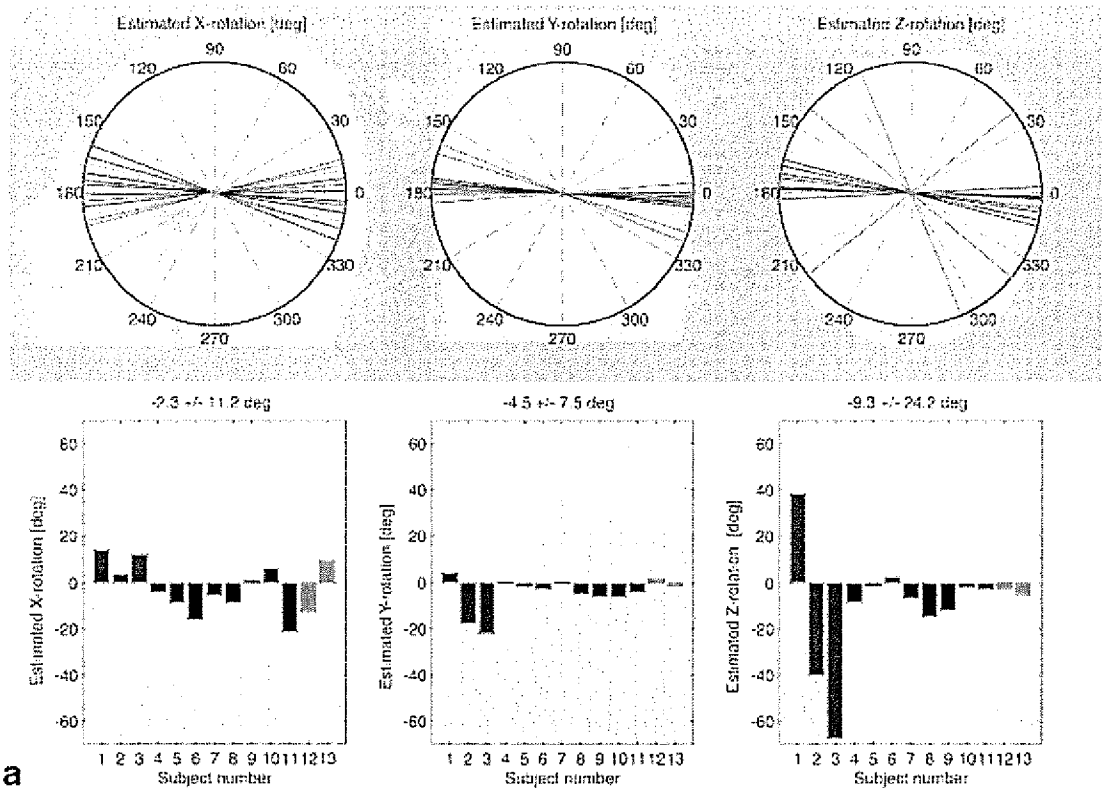
Once the geometric relationship between template and current brain surface is known, it can be used to compute the boundaries and orientations of the desired scanning volume for the current patient. The geometric description of the desired scanning volume associated with the template brain (e.g., rotation of the slice planes relative to the brain) is simply converted to the frame of reference of the current brain, using the inverse of the best-fit transformation (see Eq. [1]). The desired scan geometry relative to the current brain can then be used to acquire all subsequent scans for the current patient.

Validation

The accuracy with which our algorithm was able to determine 3D rotations between the template and current brains was evaluated by comparing the positions of anatomical landmarks in the template scan and in the pilot CSF scan resliced according to the geometric transformation from the surface matching. Ideally, these anatomical landmarks should be at the same spatial locations in the template and resliced pilot scans, and all three rotation angles derived from comparing these landmarks should be close to zero. To determine the residual differences in the x-rotation between template and current scan (rotation about an axis along the left/right direction), a line joining the most inferior point of the frontal lobe and the most superior point of the cerebellum was manually drawn on the mid-sagittal slice. The angular difference between the line drawn on the template and on the current scan was then computed. To determine the y-rotation (rotation about an axis along the anterior/posterior direction), a line joining the centroids of both eyes was determined using the eye detection algorithm described above. Finally, to determine the z-rotation (rotation about an axis along the superior/inferior direction), a line was manually drawn along the midline, on the first transaxial slice above the ventricles. In this study, we detail estimated and residual rotation parameters, which are critical in evaluating the usefulness of the method, and simply report a summary of translation and scaling parameters.

RESULTS

The algorithm to extract the brain surfaces from the current pilot scan, as well as the surface matching, worked reliably in all 25 volunteers. Although the algorithm had been tuned and optimized using the first 13 subjects (the training set), it was successfully applied with no further modification to the 12 additional volunteers who were scanned subsequently (the test set). Using separate training and test sets allowed us to determine whether our optimizations of the algorithm to yield good performance on the training set would generalize to entirely new scans after algorithmic development had been frozen. Typical processing time for the entire automatic scan prescription, including pilot scan, brain surface extraction, surface matching, and computation of desired scanning geometry, was approximately 30 sec (with processing done on a 500 MHz Compaq Alpha XP1000 Unix workstation; see Methods). Figures 4 and 5 show the individual angular differences between patients and template, as estimated from the automatic prescription, for the training and test



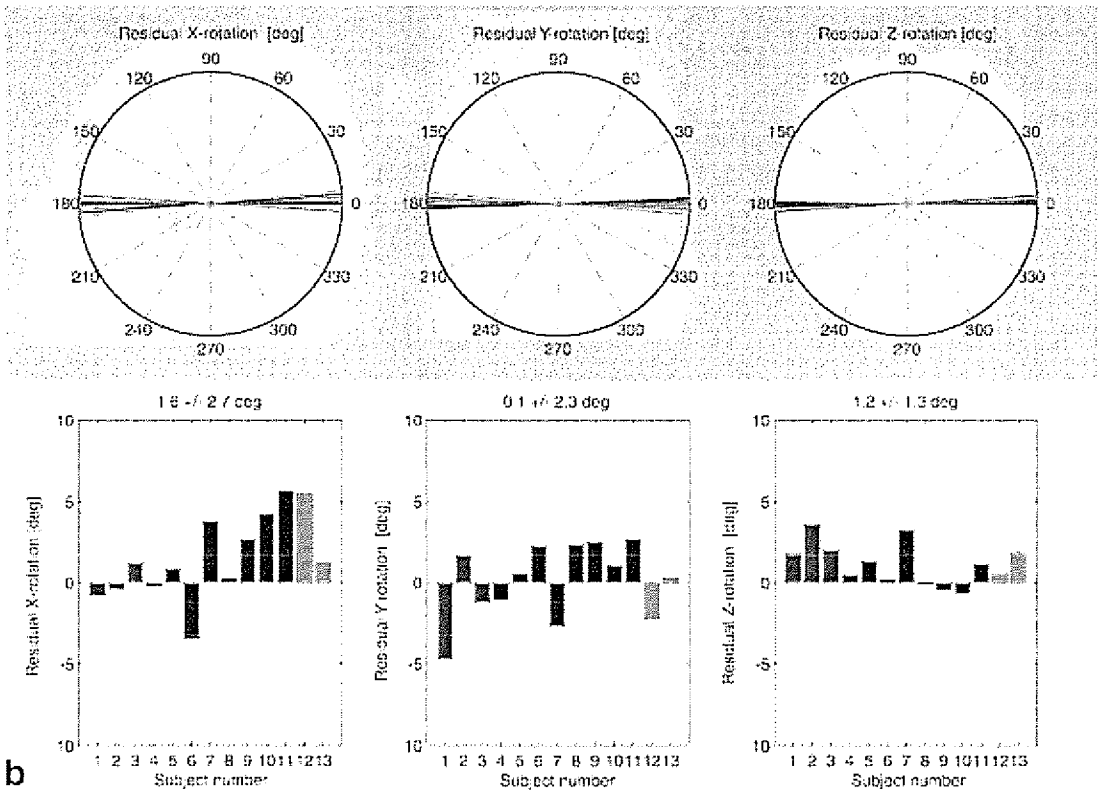
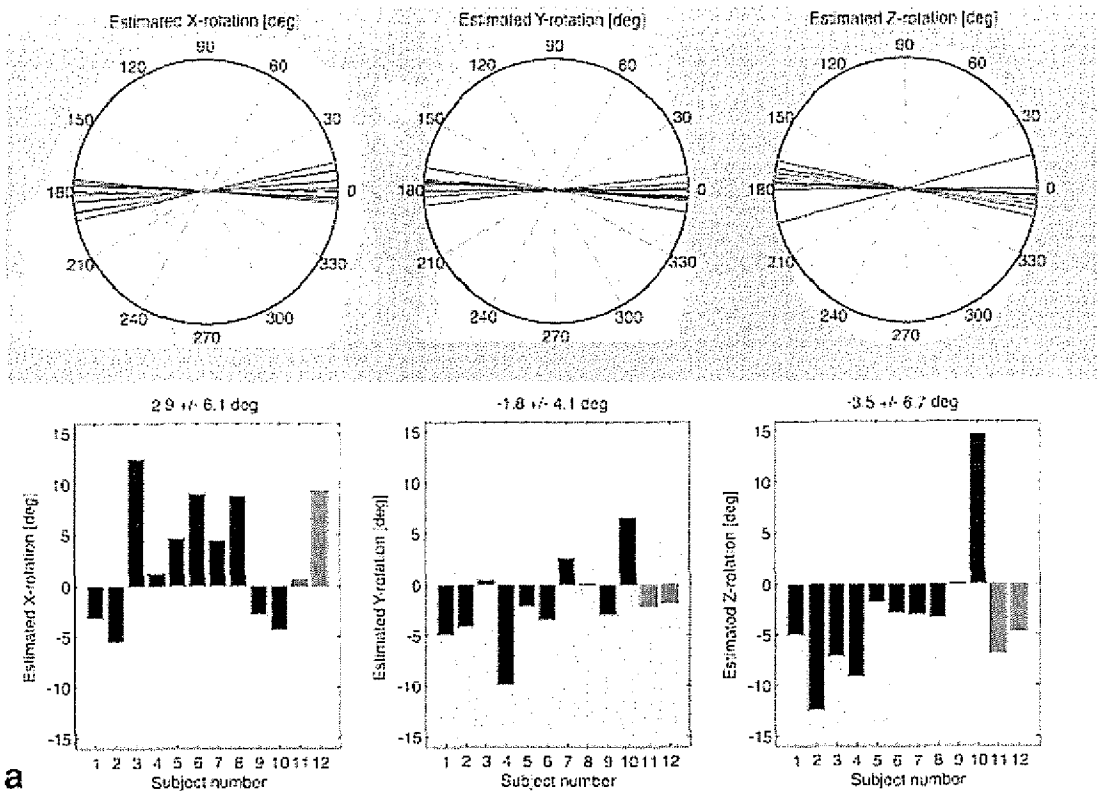


FIG. 4. Estimated (a) and residual (b) rotation angles for the 13 subjects in the training set (used to optimize the algorithm). In red are shown the three subjects who had been intentionally placed in the scanner with large rotation angles relative to typical patient positioning. In cyan are shown the two subjects who had large amounts of water in their nasal sinuses (due to sinusitis); their sinuses were incorrectly included in the brain surface by the automatic segmentation algorithm. The residual rotation angles of these five subjects fall within the range of the other subjects (dark blue).



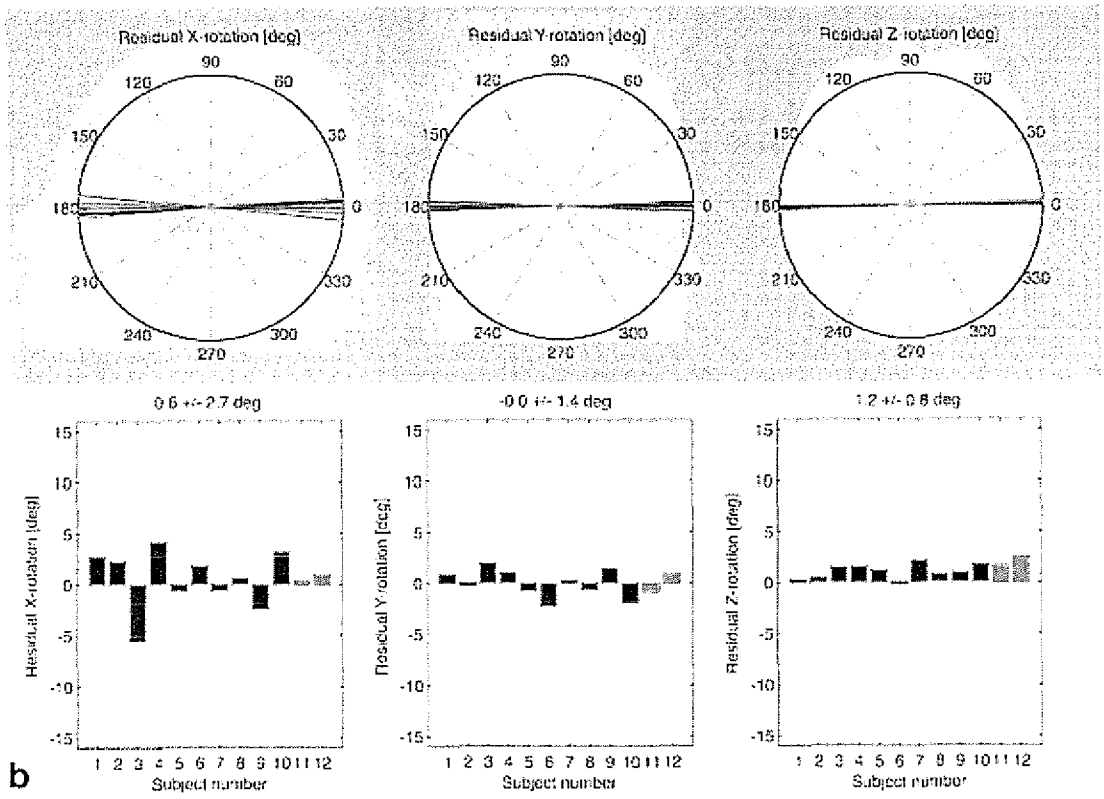


FIG. 5. Estimated (a) and residual (b) rotation angles for the 12 subjects in the test set processed without further modifications after optimizing the algorithm on the training set. The algorithm yields robust results for all 12 subjects, including two who had large amounts of water in their nasal sinuses (cyan). The ranges of residual rotation angles are similar to those obtained with the training set (Fig. 4).

Table 1
Estimated Rotation Angles, Residual Rotation Angles, and Residual Surface Matching Distance

Subject	Estimated			Residual			Distance (mm)
	X-rotation (deg)	Y-rotation (deg)	Z-rotation (deg)	X-rotation (deg)	Y-rotation (deg)	Z-rotation (deg)	
Training set							
1	14.56	4.47	38.51	−0.81	−4.68	1.82	2.54
2	3.54	−17.49	−40.01	−0.40	1.69	3.63	3.25
3	12.33	−21.89	−67.40	1.22	−1.19	2.00	3.41
4	−3.84	0.33	−8.39	−0.24	−1.07	0.50	3.17
5	−8.70	−1.54	−1.38	0.88	0.55	1.35	2.91
6	−15.92	−2.61	2.71	−3.51	2.26	0.22	3.67
7	−5.52	0.31	−6.57	3.78	−2.70	3.26	2.55
8	−8.80	−4.79	−14.77	0.25	2.34	−0.08	3.08
9	0.86	−6.14	−11.84	2.68	2.51	−0.47	2.55
10	6.07	−6.23	−1.96	4.23	1.07	−0.67	3.03
11	−21.33	−3.98	−2.79	5.67	2.70	1.15	3.11
12	−12.80	1.90	−2.28	5.49	−2.22	0.60	3.20
13	9.78	−1.06	−4.97	1.22	0.27	1.84	3.05
Average	**−2.29**	**−4.52**	**−9.32**	**1.57**	**0.12**	**1.16**	**3.04**
SD	11.23	7.47	24.19	2.68	2.33	1.33	0.34
Test set							
1	−3.16	−4.92	−5.02	2.81	0.93	0.32	2.76
2	−5.44	−4.18	−12.45	2.26	−0.24	0.52	2.71
3	12.49	0.48	−7.13	−5.58	2.00	1.53	2.90
4	1.26	−9.90	−9.14	4.17	1.11	1.58	2.93
5	4.62	−2.17	−1.76	−0.71	−0.82	1.21	2.83
6	9.07	−3.46	−2.86	1.85	−2.30	−0.15	3.02
7	4.41	2.68	−3.05	−0.66	0.26	2.20	3.09
8	8.84	0.03	−3.34	0.59	−0.70	0.83	3.63
9	−2.81	−2.96	0.04	−2.48	1.47	0.99	2.19
10	−4.32	6.54	14.71	3.26	−1.96	1.79	2.78
11	0.62	−2.13	−6.81	0.29	−0.87	1.60	3.21
12	9.34	−1.80	−4.70	0.94	0.87	2.38	3.68
Average	**2.91**	**−1.82**	**−3.46**	**0.56**	**−0.02**	**1.23**	**2.98**
SD	6.11	4.08	6.66	2.70	1.35	0.76	0.40

SD, standard deviation.

sets, respectively. As mentioned previously, the initial angles for the first three subjects are particularly large because these subjects had been intentionally placed in the scanner with severely tilted head orientations (Fig. 2). Four subjects had large amounts of water in their nasal sinuses, which were included in the brain surface by the surface segmentation algorithm. For these subjects, the second surface matching step, with the refined distance map, allowed the algorithm to ignore the sinuses and accurately recover scan orientations. For all other subjects, this second matching had no effect.

After matching, the average generalized distance between the patient and template brain surfaces was 3.04±0.34 mm (training set) and 2.98±0.40 mm (test set; Table 1). The residual rotation angles between template and reoriented pilot scans according to the geometric transformation derived by the algorithm are shown in Table 1. Note that the subjects with either large initial rotations (subjects 1–3 of training set), or water in the nasal sinuses (subjects 12 and 13 of the training set, and subjects 11 and 12 of the test set), do not appear as outliers in the results, but yield residual rotation angles within the range obtained for the other subjects. This suggests that the surface matching algorithm was robust with respect to initial conditions and to possible artifacts on the brain surface in the region of the nasal sinuses. The average 3D distance between landmarks was reduced by our algorithm from 40.5 ± 25.0 mm to 6.9 ± 2.9 mm for the training set, and from 35.8 ± 9.7 mm to 6.2 ± 2.0 mm for the test set. The scaling parameters recovered by our algorithm were 0.999 ± 0.026 for the training set (average of values for x, y, and z) and 0.998 ± 0.029 for the test set, indicating very small differences in brain size between subjects and template.

As an example of the quality of our algorithm, Fig. 2a shows MR images from one of the three volunteers with severely tilted head orientation (see also Table 1 and Fig. 4, subject 3 of training set). The matching algorithm recovered rotations of 12°, 22°, and 67° (x, y, and z) relative to the template scan. A repeat scan, acquired with the scanning geometry derived from the automatic prescription algorithm, showed symmetric brain structures (Fig. 2b) and closely resembled the template scan (Fig. 2c).

DISCUSSION

This study demonstrates the feasibility of automatic prescription of scan planes for brain MRI. The total time for

the autoprescription, including pilot scan and image processing, was approximately 30 sec, which is short enough for an automated prescan protocol. The use of single-shot FSE images, showing CSF only, allowed efficient extraction of the brain surface of the current subject with no user interaction. The surface matching algorithm proved very robust with respect to initial positioning and to surface segmentation artifacts. Our algorithm also provides a quality control measure, the generalized distance (in mm) between the current and the template brain surfaces. This measure could be used to initiate a manual procedure if it is found to be above a certain threshold, indicating a failure of the surface matching.

The emphasis of the present study is to develop a rapid and robust algorithm with reasonable accuracy. The relatively low residual rotation angles consistently measured for all subjects are within the expected error margin of a human operator who uses interactive graphical prescription tools. These residual angles might be further reduced at the cost of increased computational expense. For example, using the pilot scans at full resolution may yield slightly more accurate surface segmentation. However, since the two brain surfaces to be matched are from different subjects, interindividual differences in the brain shape may limit the potential gain in accuracy with increased spatial resolution. If the lower resolution is used in a routine implementation, scans should be acquired at reduced resolution, rather than at a high resolution followed by down-sampling.

Two special measures markedly improved the robustness of our algorithm. First, the eyes were automatically detected, and subsequently eliminated from the brain segmentation. Second, exclusion of the nasal sinuses in the second surface matching step significantly improved the matching in subjects with large amounts of water in the sinuses. In the subjects in whom the surface segmentation algorithm correctly excluded the nasal sinuses, the second matching step yielded transformation parameters identical to those from the first matching step. Because the alternate distance map (sinuses excluded) is spatially less complete than the original one, correct matching in the second matching step relies on a fairly accurate adjustment of the current brain surface to the template surface by the first matching step. Therefore, the use of two successive surface matching steps is more robust than a single-step matching algorithm that uses only the alternate distance map.

Our sample datasets included male and female subjects, both normal controls and patients, and sampled a range of possible head positions and orientations. We have previously studied the effect on our surface matching algorithm of artificially introducing a large structural defect (an ellipsoid with diameters of $10 \times 20 \times 40$ mm was cut out of the frontal lobe of one of two surfaces to be coregistered). For 11 coregistrations, we found that this artificial artifact only slightly degraded registration accuracy, by about 0.5° in x, y, and z rotation, and 0.25 mm in x, y, and z translation (3). Together with the good surface matching results reported in the present study when surface segmentation artifacts were encountered (in the region of the nasal sinuses), these findings suggest that our algorithm is robust to structural differences between the current and template brain surfaces. Furthermore, our method for overcoming surface segmentation artifacts in the nasal sinuses could be generalized to other regions of the head if future studies demonstrate frequent segmentation or registration problems for particular patient populations.

One of the consequences of the limited use of the available freedom in scanning geometry in manual prescription by human operators is a nonstandardized prescription, which yields scan orientations that vary from one patient to another. This intersubject variability can make interpretation of the images more difficult, and may ultimately lead to reduced quality of radiologic readings. Another consequence of the variability in the scan orientations is limited intrasubject reproducibility for repeat scans. Very different images may be obtained when the same subject is scanned in different sessions, such as for follow-up medical evaluations, making direct comparison of scans from different sessions unnecessarily difficult. Although a *posteriori* coregistration and realignment of follow-up scans have been demonstrated in research studies, these techniques have not yet been integrated into the standard clinical environment. Most diagnostic interpretation is performed on films or electronic displays of the scans in their native orientation, especially since post hoc reorientation may yield image degradation when the image resolution is not isotropic. In contrast, our method could be used in routine clinical settings since it corrects for patient positioning prior to scan acquisition and requires no human interaction. Furthermore, although we have included only a geometric description of scanning volume boundaries in our template, future implementations of our technique could include other geometric objects, such as locations of MR spectroscopy voxels, or a narrow range of slice positions for detailed imaging of anatomical structures such as the pituitary gland.

Our matching algorithm currently determines the translation, scaling, and rotation parameters between the reference and the new brains. Additional parameters, such as shearing, could also be determined by the same algorithm by allowing all nine parameters in the transformation matrix A (Eq. [1]) to be optimized (9). While this may improve the quality of the surface matching algorithm, it poses the problem of recovering pure rotation angles from the transformation matrix determined by the algorithm.

In summary, automatic scan prescription promises many future improvements over manual prescription, including reduced scan times, reproducible intersubject scan orientations along anatomically preferable orientations (such as the anterior-commissure posterior-commissure (AC-PC) line), and better reproducibility for intrasubject repeat studies. Our study demonstrates the feasibility of automatic scan prescription for the brain with high accuracy.

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U.S. Patent (#09/272, 436).

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